Forum Geografic - Studii și cercetări de geografie și protecția mediului (FG - S.C.G.P.M.)

The journal *Forum geografic. Studii de geografie şi protecţia mediului* (Geographical Phorum – Geographical Studies and Environment Protection Research) was founded in 2002, and it seeks to publish high quality research in the domains of geography, environment protection and other related domains. It addresses a range of issues, such as geomorphology, pedology, climatology, hydrology, human geography and environment. Its content is directed to a broad audience, including both academics and policymakers. The papers selected for publication in the journal are subject to a review process using references from universities worldwide.

The journal is currently indexed by the following databases: SCOPUS, DOAJ, EBSCO, ERIH PLUS, Index Copernicus, Scipio, CrossRef, Ulrichsweb, IGU, Google Scholar, WorldCat, ProQuest, ZDB, CNCSIS, DRJI, citefactor.org journals indexing, InfoBase index, Eurasian Scientific Journal Index, ResearchBib.

Editor-in-chef:

Sandu BOENGIU, Phisical Geography, Geography Department, University of Craiova, 13, Al. I. Cuza Street, Craiova, Romania

Liliana POPESCU, Human Geography, Geography Department, University of Craiova, 13, Al. I. Cuza Street, Craiova, Romania

Executive editor: Oana Mititelu Ionuș, Geography Department, University of Craiova, 13, Al. I. Cuza Street, Craiova, Romania

Technical editor: Cristiana Vîlcea, Geography Department, University of Craiova, 13, Al. I. Cuza Street, Craiova, Romania

Editorial Advisory Board:

Iuliana ARMAȘ, *University of Bucharest, Romania*
Sorin AVRAM, *University of Craiova, Romania*
Lucian BADEA, *The Institute of Geography, The Romanian Academy*
Dan BĂLTEANU, *The Institute of Geography, The Romanian Academy*
Zeljko BJELJAC *Geographical Institute Jovan Cvijić, Serbia*
Lucian BLAGA, *University of Oradea, Romania*
Sandu BOENGIU, *University of Craiova, Romania*
Léon BRENIG, *University of Brussels, Belgium*
Manola BRUNET, *University of Tarragona,* Spain
Sorin CHEVAL, *Henri Coandă Air Force Academy, Brașov, Romania*
Laura COMĂNESCU, *University of Bucharest, Romania*
Lóczy DÉNES, *University of Pécs, Hungary*
Philippe DONDON, *Ecole Nationale Superieure E.I.T.M.M. de Bordeaux/ Institut Polytechnique de Bordeaux, France*
Monica DUMUTRAȘCU, *The Institute of Geography, The Romanian Academy*
Dan DUMITRIU, *Al.I.Cuza University, Iași, Romania*
Recep EFE, *Balikesir University, Turkey*
Robert FOVELL, *University of California, USA*
Teodoro GEORGIADIS, *Istitute of Biometeorology (IBIMET), Bologna, Italy*
Adrian GROZAVU, *Al.I.Cuza University, Iași, Romania*
Nelly HRISTOVA, *St. Kliment Ohridsky University of Sofia, Bulgaria*
Ioan IANOŞ, *University of Bucharest, Romania*
Alexandru ILIEȘ, *University of Oradea, Romania*
Mihaela LICURICI, *University of Craiova, Romania*
Gabriel MINEA, *Institutul Național de Hidrologie şi Gospodărire a Apelor, Romania*
Oana MITITELU IONUȘ, *University of Craiova, Romania*
Emil MARINESCU, *University of Craiova, Romania*
Mirela MAZILU, *University of Craiova, Romania*
Ciprian MĂRGĂRINT, *Al.I.Cuza University, Iași, Romania*
Alexandru NEDELEA, *University of Bucharest, Romania*
Amalia NIȚĂ, *University of Craiova, Romania*
Zvi Yehoshua OFFER, *Ben-Gurion University, Israel*
Maria PĂTROESCU, *University of Bucharest, Romania*
Aurel PERȘOIU, *Emil Racovita Institute of Speleology, Romanian Academy*
Dănuț PETREA, *University of Babeș-Bolyai, Cluj-Napoca,Romania*
Liliana POPESCU, *University of Craiova, Romania*
Kumar Rai PRAVEEN, *Banaras Hindu University, India*
Maria RĂDOANE, *Ștefan cel Mare University, Romania*
Milan RADOVANOVIĆ, *Geographical Institute Jovan Cvijić, Serbia*
Khaiwal RAVINDRA, *School of Public Health, PGIMER*, Chandigarh, India
Daniela ROŞCA, *University of Craiova, Romania*
Daniel SIMULESCU, Agentia Nationala pentru Arii Naturale Protejate
Igor SIRODOEV, Universitatea "Ovidius" din Constanţa, *Romania*
Fábián Ákos SZABOLCS, *University of Pécs, Hungary*
Cristina ȘOȘEA, *University of Craiova, Romania*
Magdy TORAB, *Alexandria University, Egypt*
Marcel TÖRÖK – OANCE, *West University of Timișoara, Romania*
Cristiana VÎLCEA, *University of Craiova, Romania*
Alina VLĂDUȚ, *University of Craiova, Romania*
Nenad ŽIVKOVIĆ, *Belgrade University, Serbia*
Martina ZELENAKOVA, *Technical University of Kosice, Slovakia*
Zbigniew ZWOLIŃSKI, *Adam Mickiewicz University (Poznan), Poland*

Associate Editors:

Slavoljub DRAGIĆEVIĆ, Faculty of Geography, Belgrade University, Studentski trg 3/3, Belgrade, Serbia

Vesna LUKIĆ, Demographic Research Centre, Institute of Social Sciences, Kraljice Natalije 45, Belgrade, Serbia

Nina NIKOLOVA, Faculty of Geology and Geography, "*St. Kliment Ohridsky*" University of Sofia, Tzar Osvoboditel Blvd. 15, Sofia, Bulgaria

Founding Editors: Boengiu S., Marinescu E., Pleniceanu V., Tomescu V., Enache C.

Cover photo: *Balta Lată (by Mihaela Licurici)*

For instructions for authors, subscription and all other information please visit our website
http://forumgeografic.ro
before submitting any papers please select the section *Publishing rules* from the About page and read thoroughly the submission instructions for authors

ISSN 1583-1523 (print)
ISSN 2067-4635 (online)
DOI prefix: 10.5775

Instructions for Authors

Article submission

In order to disseminate the research results in the field, researchers, scholars and professionals are welcome to submit an electronic version of the manuscript (in Microsoft Office Word format) to the editorial office (forum.geografic@gmail.com).

Submission requirements: The submission of an article for publication in our journal implies that the article has not been published before, nor it is being considered for publication in other journals. Authors are responsible for the content and the originality of their contributions. In order to be published, articles must be thoroughly researched and referenced.

IMPORTANT: All papers must be submitted in electronic format, only in English language.

Copyright statement

By submitting a scientific work to ***Forum geografic*** the submitters agree to declare the following:

- the submitted work belongs exclusively to the declared authors;
- the submitted work represents original scientific research;
- the submitted work has not been published or submitted for publishing to another journal;
- if the submitted work is published or selected for publishing in ***Forum geografic***, the authors waive any patrimonial claims derived from their authorship for the submitted work; the authors retain the moral rights for their submitted work, as granted under the Romanian applicable law; also, the authors agree to refrain from ulterior submitting of the work to other journals.

The submitters agree to be solely held accountable in case of breaching the above terms and to defend the representatives of ***Forum geografic*** in the event of a lawsuit related to the submitted work.

When submitting a paper the authors are required to print, fill and send a scanned copy of this declaration.

Privacy statement

The submitted personal data, such as names or email addresses, are used only for the declared purpose of the ***Forum geografic*** journal (publishing original scientific research) and are not available to third parties.

Manuscripts are received at all times. However, in order to have your article published in the current year, the manuscripts must be submitted until the 15th of February for the first issue of the current year and until the 1st of September for the second issue.

Article format

All manuscripts must be edited entirely in English. Articles must include:

- Title
- Author's name(s). For each author you must mention the author's scientific title, his affiliation (institution) and e-mail address;
- Abstract (maximum 300 words);
- Keywords (not more than 5-6 words);
- Acknowledgments (if any);
- Main body of text (structured according to Introduction, Data & Methods, Results & Discussions, Conclusions);
- Illustrations (graphs, diagrams, maps, photos – should have indications of their positions in the text and title written in English) must be also submitted in electronic format, preferably in JPG, PNG or BMP format and must be referred to as Figures, which should be numbered with Arabic numbers.
- Tables must be numbered with Arabic numbers and should not repeat data available elsewhere in the text.
- References must be indicated in the text, between brackets and they must include the author's name and the date of the publication (Popescu, 2000). When three or more authors are referred, they will appear in the text as follows: (Popescu et al., 1997). References must be listed in alphabetical order at the end of the text.

The following style sheet is recommended:

- for journals:

Miletić, R., Lukić, V., & Miljanović, D. (2011). Deindustrialization and structural changes in commuting flows in Serbia. *Forum geografic*, X(2), 244-254. doi:10.5775/fg.2067-4635.2011.009.d

- for books:

Bran, F.,Marin, D., & Simion, T. (1997). Turismul rural. Modelul european, Editura Economică, București

- for papers from conference proceedings:

Deci, E. L., Ryan, R. M., (1991), A motivational approach to self: Integration in personality. In R. Dienstbier (Ed.), *Nebraska Symposium on Motivation: Vol. 38. Perspectives on motivations* (pp. 237-288). Lincoln: University of Nebraska Press.

Review process

All the manuscripts received by the editors undergo an anonymous peer review process, necessary for assessing the quality of scientific information, the relevance to the field, the appropriateness of scientific writing style, the compliance with the style and technical requirements of our journal, etc. The referees are selected from the national and international members of the editorial and scientific board, as well as from other scholarly or professional experts in the field. The referees assess the article drafts, commenting and making recommendations. This process leads either to acceptation, recommendation for revision, or rejection of the assessed article. Editors reserve the right to make minor editorial changes to the submitted articles, including changes to grammar, punctuation and spelling, as well as article format, but no major alterations will be carried out without the author's approval. Before being published, the author is sent the proof of the manuscript adjusted by editors. If major revisions are necessary, articles are returned to the author so that he should make the proper changes. Authors are notified by email about the status of the submitted.

Forum Geografic - Studii și cercetări de geografie și protecția mediului
www.forumgeografic.ro DOI: 10.5775/fg

CONTENTS

Volume XXI, Issue 2 / December 2022

Characteristics of volcanic mountains morpho structure of Transcarpathia, Ukraine
Mykhailo MYKYTA, Maryana SALYUK, Roman SLAVIK, Mykola KARABINIUK, Vasyl LETA 97

Features of the morphology and dynamics of the shallow-island part of the Dolgaya Spit (the Sea of Azov)
Viacheslav KRYLENKO, Marina KRYLENKO 109

Estimating organic carbon in soils modified by technical processes in Kula Municipality (Bulgaria)
Alexander SARAFFOV, Petko BOZHKOV, Borislav GRIGOROV 123

Morphometry and Topographic Wetness Index Analysis for flood inundation mapping using GIS in Mata Allo Watershed, South Sulawesi, Indonesia
UCA, Mustari LAMADA, Sukri NYOMPA, Nurul Afdal HARIS 133

Covid-19 lockdown effect on aerosol optical depth in Delhi National Capital Region, India
Sharma VIPASHA, Ghosh SWAGATA, SHAHNAWAZ, Rai KUMAR PRAVEEN, Singh SULTAN 146

Solid waste management as an urban area regulation in Algeria. Case of El-Khroub city
Naziha LAMRI, Amna BELAYADI, Faiza ABBAS 158

Ecosystem behaviour face to climatic changes and anthropogenic actions. Case study: a north-eastern urban wetland, Tunisia
Faiza Khebour ALLOUCHE, Rania AJMI, Safa Belfekih BOUSSEMA, Gheorghe ȘERBAN 172

Ecosystem services versus wellbeing – implications for sustainable tourism: the host perspective
Anna DŁUŻEWSKA, Zbigniew PODGÓRSKI, Andrea GIAMPICCOLI 186

International migration and impacts on the spatial dynamics of Guercif city (eastern Morocco)
Mohammed ELYAAGOUBI 201

The impact of net migration on financial inclusion in Romania
Stefan JOHNSON 208

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December 2022**), pp. **97-108**
http://dx.doi.org/**10.5775/fg.2022.081.d**

Characteristics of volcanic mountains morphostructure of Transcarpathia, Ukraine

Mykhailo MYKYTA[1], Maryana SALYUK[1], Roman SLAVIK[1], Mykola KARABINIUK[1], Vasyl LETA[1]*

[1]Faculty of Geography, Department of Physical Geography and Environmental Management, Uzhhorod National University, Universytets'ka street, 14, Uzhhorod, Ukraine
* *Corresponding author*: vasyl.leta@uzhnu.edu.ua

Received on 30-04-2022, reviewed on 26-08-2022, accepted on 07-10-2022

Abstract

The study presents a detailed geomorphological characterization of the volcanic mountains of Transcarpathia. Materials of previous geological researches, including the Transcarpathian geological exploration expedition, supplemented by the results of our own field researches, are systematized. Based on the analysis of relief forms and taking into account geomorphological and tectonic factors, Vyhorlat-Gutyn morphostructure of the second order is divided into morphostructures of the third order: Poprychny, Antaliv-Synyatska, Velykyi Dil, Tupy and Oash, which in turn are divided into morphostructures of lower orders. The Mukachevo morphostructure of the second order is composed of the following morphostructures of the third order: Beregovo hills, Kosino-Biganski hills, volcanic remains (Shalanka, Chorna Gora). Based on a detailed analysis of the collected materials, it was determined that the main role in shaping the modern relief of volcanic mountains belongs to channel and temporary water flows and weathering processe; consequently, river valleys and weathering surfaces were formed, which are the most important morphosculptures. On the basis of morphological and structural-lithological approach, as well as own field research, a geomorphological map of the volcanic mountains mountains of Transcarpathia on a scale of 1: 100,000 was compiled.

Keywords: *geological structure, morphology, morphostructures, andesites, basalts, liparites, Vygorlat-Gutyn ridge*

Rezumat. Caracteristicile morfostructurilor munților vulcanici din Transcarpatia, Ucraina

Studiul prezintă o caracterizare geomorfologică detaliată a munților vulcanici din Transcarpatia. Sunt sistematizate materiale ale cercetărilor geologice anterioare, inclusiv expediția de explorare geologică transcarpatică, care sunt completate cu rezultatele cercetărilor proprii de teren. Pe baza analizei formelor de relief și luând în considerare factorii geomorfologici și tectonici, morfostructura Vyhorlat-Gutyn de ordinul doi este împărțită în morfostructuri de ordinul al treilea: Poprychny, Antaliv-Synyatska, Velykyi Dil, Tupy și Oash, care la rândul lor sunt împărţite în morfostructuri de ordin inferior. Morfostructura Mukachevo de ordinul doi este compusă din următoarele morfostructuri de ordinul al treilea: dealurile Beregovo, dealurile Kosino-Biganski, vestigii vulcanice (Shalanka, Chorna Gora). Pe baza unei analize amănunțite a materialelor colectate, s-a stabilit că rolul principal în modelarea reliefului actual al munților vulcanici revine văilor și cursurilor temporare de apă, precum și intemperiior, care au format văile râurilor și suprafețele de modelare, care sunt cele mai importante morfosculpturi. Pe baza abordării morfologice și structural-litologice, precum și a cercetărilor de teren proprii, a fost întocmită o hartă geomorfologică a munților vulcanici din Transcarpatia la scara 1: 100.000.

Cuvinte-cheie: *structura geologică, morfologie, morfostructuri, andezite, bazalte, liparite, creasta Vygorlat-Gutyn*

Introduction

Volcanic mountains of Transcarpathia are the youngest orographic formation in the system of the Ukrainian Carpathians and at the same time, in comparison with the neighboring territories, are insufficiently studied. During the 19th-20th centuries, researches of the geological structure of the territory were carried out, along with thematic works, such as geophysical research, developed stratigraphic schemes. This contributed to a detailed study of the mineralogical and petrographic composition of rocks. Subsequently small-scale and large-scale studies supplemented the materials on geological study, neotectonics and paleogeographic analysis of the territory. These materials have almost no information about geomorphological features and processes, landforms of volcanic mountains. Some information about the geomorphological structure of individual territories or districts is partially reflected in scientific publications. The most important contribution to the study of Transcarpathian volcanism was made by Maleev (1964), Merlich and Spitkovskaya (1974). Geological and tectonic processes were studied by Hofstein (1995), Alfer'ev (1968), Merlich and Spitkovskaya (1974), Kostyuk (1961), Sobolev, Vartanova, Gorbachevskaya (1947), Yermakov (1948).

The practical significance of the results. The relevance of this work is due to insufficient development of the topic, the lack of a comprehensive geomorphological study of the volcanic mountains of Transcarpathia. Therefore, there is a need to systematize and supplement existing materials and knowledge. This study is also relevant because the geomorphological study of the territory today is mostly descriptive, moreover morphological characteristics and its connection with the main factors of relief formation remain practically absent. A complex combination of volcanic structures and tectonic elements has determined the modern geomorphological structure of the territory, which by the specific nature of volcanic activity, structural and morphological features require a separate study.

The collected factual material on the research issues can be used in further geomorphological and paleogeographic studies in the region, the characteristics of relief assessment for engineering, environmental and recreational purposes, the development of anti-erosion measures and more.

Study area. The southernmost volcano of the Carpathian ridges is the powerful Vygorlat-Gutyn volcanic ridge, one of the links of the Neogene volcanic formations of the Carpathian Arc. Within Transcarpathia, the ridge stretches in a narrow strip from northwest to southeast, from Uzhgorod to Khust. The length of the strip is about 120 km, the width - from 8 to 25 km. Along the southern slopes of the Vyhorlat-Hutyn ridge, there is the Chop-Mukachevo alluvial plain, against which rises the Beregovo hills and island volcanic mountains. They are located west of Berehove, between the villages of Velyka Bigan and Zapson and near Vynohradiv (Fig. 1).

The structural-volcanic relief of the volcanic mountains of Transcarpathia was formed as a result of the interaction of oppositely directed endogenous and exogenous forces. The former significantly prevailed, forming the main geological structures. Morphostructure is understood as a complex of relief forms and geological structure, historically connected into a single unit by common conditions of development. According to Kruglov, Smirnov, Khyzhnyakov (1985), Palienko (1992), the East Carpathian morphostructure of the first order is divided into seven morphostructures of the second order, among which the Vygorlat-Gutyn and Transcarpathian morphostructures are distinguished (Palienko, Sokolovsky 1979), as well as Mukachevo and Solotvyno (Gerenchuk 1981).

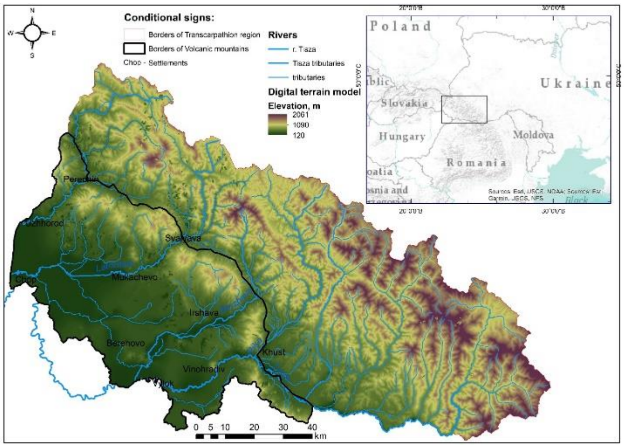


Fig. 1. Map of study area

Materials and Methods

During the study of the geomorphological structure of the volcanic mountains of Transcarpathia, a number of methods of both general and specific scientific knowledge were used. In close contact with the basic natural sciences, geomorphology makes extensive use of the methods of various natural sciences. However, more important in geomorphological research are certain methods that underline the sciences of the geological complex, and sciences that study the spheres of the Earth's outer shell.

In geomorphological science, depending on the organization of work, there are methods of field geomorphological research (expeditionary), which are based on route surveys of the territory and combined with geomorphological mapping and in-house methods aimed at processing field materials, their generalization and terrain modeling (Karpenko 2009).

The morphological method used in the current research was to determine the external features of the forms and types of the volcanic mountains relief of Transcarpathia. It was used to establish and describe narrow ridges, cone-shaped and domed peaks, hills, V-shaped river valleys, and so on. There is no doubt that this method of research was necessary to combine the analysis of morphology of ancient and modern relief creation processes in the study area, which allows to objectively assess the stability of relief elements.

The morphometric method of research, which is a variant of the morphological method, is based on quantitative information about geomorphological objects to identify and describe them. Based on this, specific morphometric descriptions are made, which are necessary for understanding the basic laws of formation and development of the relief of the earth's surface. For this purpose, morphometry uses any quantitative information about the relief of the study area. Morphometric indicators are needed primarily for the development of measures in areas with dangerous relief-forming processes.

For this research quantitative indicators of the relief were analyzed using GIS packages - ArcGIS and graphics editors CorelDraw and Adobe Photoshop. It was important to correctly build the technological process of vectorization of cartographic data. Preparation of raster cartographic materials was carried out according to the technological scheme proposed by Dziuba (2000).

Since the geomorphological structure of the volcanic mountains of Transcarpathia is inextricably linked with the geological features of the territory and tectonic structures, an important approach in the study of these relationships is the morphostructural method. The method is used to study the relationship between the irregularities of the earth's surface and the geological structure of the study area. The morphoneotectonic research method was used to identify the links between landforms and geological deposits and to study the direction of tectonic movements and their reflection in geomorphological processes (erosion, accumulation, etc.). The morphodynamic method of cognition was used for the analysis of exogenous processes of the territory and their influence on the geomorphological structure.

On the territory of Transcarpathian volcanic mountains, reconnaissance routes were selected on the basis of topographic (scale 1:25,000, 1:50,000) and geological maps (1: 200,000), maps of quaternary deposits (1: 100,000) and stock materials of the Transcarpathian Geological Exploration Expedition. Due to the large size of the study area, key areas were selected for such routes, which represent the main elements and forms of relief of the volcanic mountains of Transcarpathia. Field geomorphological studies have been conducted for several years within the following areas:

1. route through the territory of the Poprychny massif;
2. study of the Antaliv-Synyatsky massif;
3. route through the Velykyi Dil massif;
4. field research of the Tupy ridge territory;
5. route through the territory of the Oash massif;
6. study of volcanic remains of the Chop-Mukachevo lowland (Fig. 2).

The purpose of the field research was to identify morphostructures, basic forms and types of relief, survey of natural outcrops, study river valleys and their deposits as well as other elements. At the same time, attention was paid to the peculiarities of the expression of morphostructures in the relief and their comparative analysis was performed. The influence of hydrographic objects of the territory, soil and vegetation cover and economic development on the intensity and dynamics of modern geomorphological processes was also observed.

During the desk stage, a detailed analysis of the available materials was carried out, a geomorphological map of the volcanic mountains of Transcarpathia at a scale of 1: 100,000 was compiled (Fig. 3).

Results and Discussion

The study area is located within the Vyhorlat-Gutyn and Mukachevo morphostructures of the second order. The Vyhorlat-Gutyn morphostructure was formed as a result of powerful volcanic eruptions in the Upper Miocene and Pliocene. It is formed by Kuchavsky, Antalivsky, Makovytsky, Matekivsky, Sinyatsky, Obavsky, Martynsky and Buzhorsky volcanic complexes. They are composed mainly of andesites, andesite-basalts, andesite-dacites, basalts, and their tuffs.

Transverse terraced valleys of the Uzh, Latorytsia, Borzhava and Tisza rivers divide the volcanic ridge into separate massifs. West of the river Uzh there is the Vygorlat ridge, the main part of which is located within Slovakia.

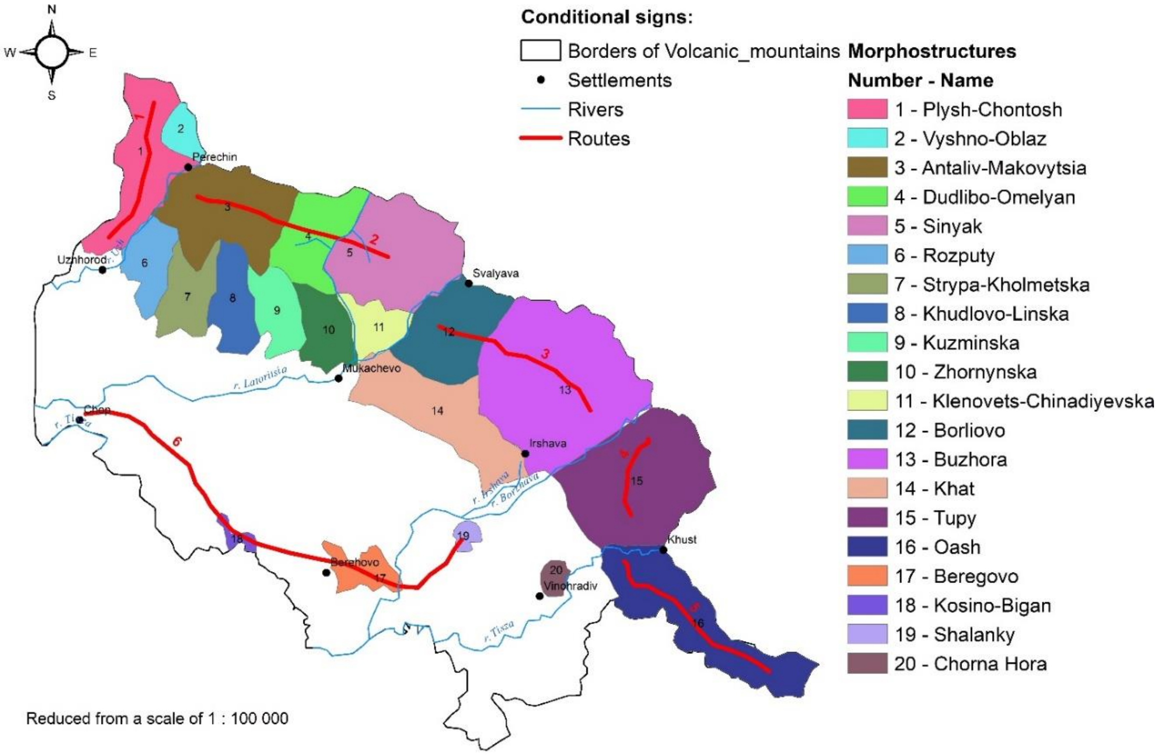


Fig. 2: Map of the morphostructures of the Volcanic mountains and survey routes

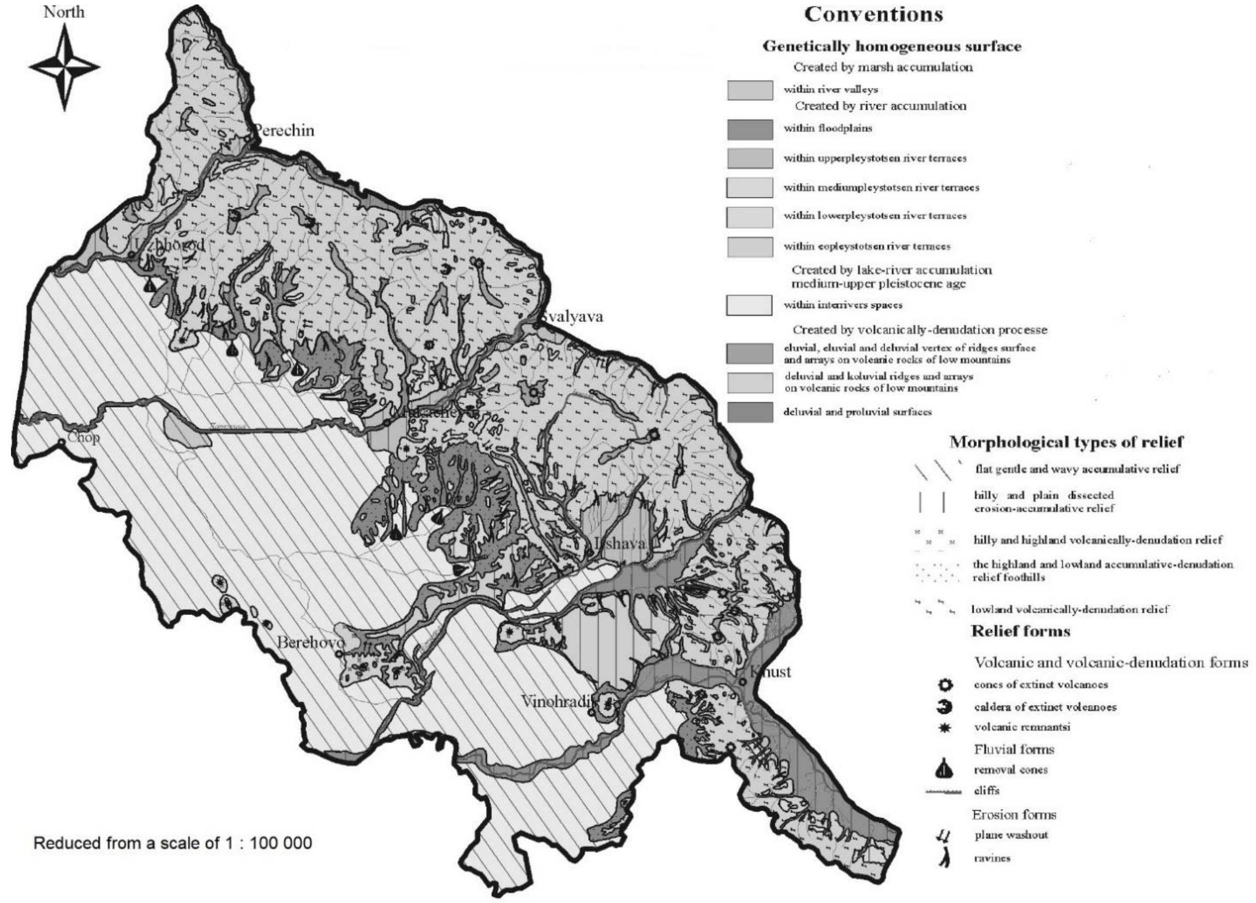


Fig. 3: Geomorphological map of Volcanic mountains of Transcarpathia, Ukraine

The group of mountains between the valleys of the Uzh and Latorytsia rivers is the Antalivska Polyana massif, or Makovytsia, with individual peaks close to 1,000 m (Makovytsia - 978 m, Pleska - 993, Serednya - 981 m). Between the Latorytsia and Borzhava rivers there is a massif Velykyi Dil with Mount Buzhora (1,086 m), which is the highest peak of the volcanic mountains within Transcarpathia. The Tupy massif, acquiring a meridional direction relative to the main ridge, is located between the valleys of the Borzhava and Tisza rivers. Dome-shaped peaks Klobuk (856 m) and Tupy (878 m) rise along the ridge. South of the city of Khust, behind the Tisza River there is the Oash massif, which stretches into Romania.

The morphology of the Vygorlat-Hutyn ridge is due to the multiphase of accumulative volcanic activity and long periods of erosion and denudation of the original forms of volcanic structures. As already noted, the most characteristic features of the ridge are its asymmetric structure: with short and steep northern, northeastern and eastern slopes and elongated and gentle opposites, which are oriented towards the plain. The highest peaks are located closer to the northern, northeastern and eastern edges of the Vyhorlat-Hutyn ridge, in particular, Poprychny (995 m), Antalivska Polyana (988 m), Makovytsia (976 m), Dunavka (1018 m), Dakhmaniv (1016 m), Martynsky Kamin (970 m), Buzhora (1083 m), Bystra (1038 m), Tupy (778 m), Tovsty (819 m), Frasin (826 m), etc. These are volcanoes of the central type, which have preserved their characteristic conical shape and significant relative elevations (400-500 m) over the surrounding area with a classically pronounced radial hydro network. The tops and upper parts of the slopes of central volcanoes are sediments, smoothed, and flat watersheds are structural denudation surfaces of lava flows, which are prepared by denudation and somewhat eroded (Kamanin L, Ivanova 1954; Matskiv et.al. 2001).

Areas of tuff accumulation form wide watershed surfaces with absolute heights of 350-650 m and values of relative elevations up to 200-400 m. The slopes are generally smoothed, but dissected by a small bright system. Extruded tents, slag cones, subvolcanic and subintrusive rods, hypobisal bodies are well expressed in relief. They form conical vertices, the shapes of which are close to isometric, elliptical with sizes from 0.3-0.5 to 1.0-2.0 km.

The morphology of the river valleys that divide the Vygorlat-Gutyn ridge is determined by the lithology of blurred rocks. The valleys laid in massive lavas are deep, steep slopes with a V-shaped profile, while those in the tuffs are wide, trough-shaped.

The Mukachevo morphostructure is composed of Neogene molasses and Sarmatian volcanics, which are almost everywhere covered by quaternary sediments. The surface of the morphostructure is mainly a flat lowland alluvial plain, the absolute heights of which increase in the area near the Vygorlat-Gutyn ridge. In general, this area is a low terrace of the Tisza River and its tributaries, which rises above the current water level in rivers by an average of 5-6 m. The absolute heights of the plain are 115-120 m in the area adjacent to the Vygorlat-Gutyn ridge, descending to 105 m on the banks of the Tisza near the town of Chop.

The Mukachevo morphostructure is separated from the Vygorlat-Hutyn ridge by a strip of foothills, which in the Mukachevo-Irshava section form two flat spurs towards the lowlands. There are several ledges, which are inclined to the lowlands and divided by small tributaries of the rivers Latorytsia, Borzhava, as well as a number of shafts with wide, flat or domed peaks (Gerenchuk 1981). The relief of the morphostructure includes some dome-shaped volcanic mountains and remnants - Beregovo hills, Kosino-Biganski hills, Palanka, Drysinskaya, Chorna Gora (568 m), Shalanka (372 m) and others.

We propose to divide the Vygorlat-Gutyn morphostructure of the second order into morphostructures of the third order. From the north-west to the south-east, we distinguish the following morphostructures: Poprychny, Antaliv-Synyatska, Velykyi Dil, Tupy and Oash, which, in turn, are divided into morphostructures of lower orders.

The Mukachevo morphostructure of the second order includes the Beregovo mountain range, the Kosino-Bigansky hills, volcanic remains (Shalanka, Chorna Gora), which respectively are lower order morphostructures.

The Poprichny morphostructure occupies the area between the state border with Slovakia and the valley of the Uzh river. It was formed on the homonym volcano, which is composed of andesites, andesite-dacites, rhyolites and their tuffs of the Antalivsky volcanic complex. The territory of the morphostructure is characterized by low-mountainous volcanic-denudation relief. From the west, along the state border, the watershed ridge Poprychny Verkh with domed, sometimes elongated peaks can be clearly seen (mountains Golytsia - 983.1 m, Vitrova Skala - 1024.9 m, Poprychny Verkh - 995.2 m, Chertezh - 903.8 m). The slopes of the ridge are mostly convex. The exception is the northeastern slope, which has a complex convex-concave transverse profile. The steepness of the slopes' averages 9-20º and more. The ridge is composed of fine-porphyry andesites and their tuffs with a thickness of 260 m, which are overlapped by periclinal lava flows (up to 200 m) of various porphyry andesites. It is divided by the upper reaches of the rivers Syrova, Benyatinska Voda, Kamenichka, Syry Potok, where deep erosion predominates. River valleys are characterized by steep slopes, V-shaped transverse profile, there are no floodplains. In the southern part of the Poprychny morphostructure, from the Poprychny Verkh ridge to the Uzh river valley, two low-mountain ridges with Plyshka (693.4 m) and Yavorova (701.1 m) peaks stand out, forming the fourth-order Plysh-Chontosh morphostructure. The maximum absolute heights of the morphostructure range from 440-700 m. The main characteristic of the lithological features of this morphostructure, as well as that of Poprichny, is the dominance of sediments of the Antalivsky volcanic complex, represented by andesites, andesitic basalts, andesitic dacites and their tuffs. The south-eastern part of the morphostructure differs, where eruptive bodies of fine-porphyry andesites stand out on the left bank of the Syry Potok. The Chontosh and Plyshka ridges are separated by the Syry Potok river, which flows in a south-easterly direction and flows into the Uzh river near the village of Kamenitsa. The river valley is narrow, with steep (more than 20º) slopes. The ridges are strongly dissected by tributaries of the Syry Potok river. Their slopes are mostly convex, sometimes concave, with a steepness of 8-20º.

The interfluve of the Domarach and Dvernytsky rivers is occupied by the Vyshno-Oblaz morphostructure of the fourth order, which is represented in the relief by a highly dissected ridge with steep northern slopes (maximum absolute heights 358.8 m, 331.6 m) and a domed mountain Vyshny Oblaz (357.2 m).

The Antaliv-Synyatska morphostructure occupies the interfluve of the Uzh and Latorytsia rivers. Its length is up to 43 km, width - 25-27 km. Orographically, it is characterized by short and steep northern, northeastern slopes in the direction of the Turya River valley and gentle and elongated southern, southwestern slopes in the direction of the Chop-Mukachevo lowlands. The highest absolute heights are in the northern and north-eastern part of the morphostructure, the growth of which can be traced from the north-west (from the Uzh river valley) to the south-east (to the Latorytsia river valley).

From the valley of the Uzh river to the Koblyky tract, we find the ridge Sinatoriya (691.9 m; mountains Rozhok - 546.4 m; Sokolych - 812.0 m), the Lypova Skelya ridge (896.0 m), mountain Makovytsia (976.0 m). The southern part of this ridge is characterized by conical peaks (Antalivska Polyana - 968.3 m, Dil - 793.5 m). The ridges are strongly dissected, massive and mostly sub-latitudinal. The surfaces of the peaks are rounded, wide, flat and are structural denudation surfaces of lava covers and streams, modelled mainly by deep erosion. Slopes are usually convex, concave, convex-concave with steepness from 3-5º (top surfaces) to 35º (near the tops of the Klokotyva stream). The north-eastern slopes of the ridges are divided by numerous streams of the Verkhniy, Velyka Ruzha, Kostyliv, Bystryk, south-eastern slopes - the valleys of the streams Tsygany, Solotvinsky, Stara and their numerous tributaries.

In the upper reaches of the Vyznytsia (tributary of Latorytsia) and Poluy rivers (tributary of Mala Latorytsia) the absolute heights decrease to 570-700 m (tracts Koblyky, Podklykuchky, Omelyany, Yavornyk). The area is dominated by medium-divided massive ridges with narrow elongated peaks (Podklikuchka tract, the interfluve of the Polyuy and Vyznytsia rivers). Convex, convex-concave slopes with a steepness of 3-7º on flat top surfaces up to 30º in the valley of the Vyznytsia river predominate.

The highest part of the Antaliv-Synyatska morphostructure is located between the valleys of the Vyznytsia river with the tributary Lamovani and the valley of the Latorytsia river. It is represented by the Tovsty, Shiyka, Plyshka and Sinyak ridges, which extend almost meridionally. The Tovsty, Shyika and Plyshka ridges include the following peaks: Chalovisty, 860.0 m; Neck, 702.9 m; Plishka 992.0 m; Obavsky Kamin, 979.2 m. The Sinyak ridge includes the Biliy Kamin, 961.0 m; Dunauka, 1018.8 m; Solochynskyi Dil, 980.7 m; Serednyi Verkh, 980.7 m. These ridges are divided by deeply incised valleys of the rivers Vyznytsia, Obava, Matekova, Tysanyk, Oblazny, Luh, Bystra, which in very large areas have very steep and steep slopes. Apical surfaces are rounded, wide and wavy.

The southern and southwestern part of the Antaliv-Sinyatskaya morphostructure is divided by numerous tributaries of the Latorytsia river into elongated ridges from north to south, where absolute heights of 300-500 m predominate. Absolute and relative heights, as well as the steepness of the slopes gradually decrease with the approach to the Chop-Mukachevo plain. Against the background of these ridges, dome-shaped peaks rise, the structure of which involves powerful strata of andesites and andesito-dacites (Kravchuk, 2008).

Sediments of the Kuchavsky (southeastern part), Antalivsky, Makovytsky, Matekivsky, Synyatsky, and Obavsky volcanic complexes take part in the construction of the Antaliv-Sinyatska morphostructure. These are andesites, andesite-basalts, rhyodacites, dacites, andesite-dacites and their tuffs. The total thickness of the deposits of each complex is from 400 to 700 m.

Within the Antaliv-Synyatska morphostructure of the third order, the following morphostructures of the lower order can be distinguished: Antaliv-Makovytska, Dudlibo-Omelyanska, Tovsty-Sinyak, Rozputy-Chinadiyevska.

The Antaliv-Makovytsia morphostructure of the fourth order in the west and northwest is limited by the valley of the Uzh river, in the north and northeast - by the valley of the river Turya, on the east – by the upper reaches of the rivers Bystryk (tributary Turya) and Stara (tributary Latorytsia), and in the south-west and south - by the line of villages Orikhovytsia – Yarok – Verkhne Solotvino – Antalovtsi. In its western part there is the Sinatoria ridge with the peaks of Rozhok (546.4 m), Sokolych (812 m), Antalovetska Polyana (968.3 m), Dil (793.5 m). To the east stretches the ridge Lypova Skala with the peaks of Makovytsia (976.0 m) and Zakruzhy (687.0 m). The northern and north-eastern slopes of the ridges are strongly dissected by the tops of numerous tributaries of the Uzh and Turia rivers (Vorocheva, Verkhniy, Klokotyva, Velyka Ruzha). Convex and convex-concave slopes with a steepness of up to 35º predominate. The southern and southwestern slopes are less dissected than the northeastern ones. Their steepness does not exceed 15-20º. The slopes are mostly convex, although straight. The apical surfaces of the ridges are rounded, often wide and bumpy. River valleys that divide ridges are narrow, sloping, symmetrical, often V-shaped. The Antaliv-Makovytsia morphostructure is composed of deposits of the Antalivsky and Makovytsky volcanic complexes. The Antalivsky complex, represented by andesites and their tuffs, andesite-dacites, rhyolites and their tuffs, forms the Sinatoria ridge and the lower part of the Lypova Skala ridge. The Makovytsky complex forms the upper part of the Lypova Skala ridge. It is composed mainly of medium porphyry dipyroxene andesites, less of andesite-basalts, tuffs of andesites, which with angular mismatch lie on the Paleogene rocks of the Magura flysch, and with a stratigraphic break - on the rocks of the Antalivsky complex.

The Dudlibo-Omelyan morphostructure. The western and northwestern borders of this morphostructure are the interfluve of the Stara and Bystryk rivers, the northern border runs along the valley of the Turia river, the northeastern border runs along the valley of the Mlynska river and the valley of the Lamovani river (a tributary of the Vyznytsia). Vyznytsia, and south-west - along the villages of Goydosh-Lintsi-Patskanyovo-Rostovyatytsia-Bobovyshche-Ilkovytsia-Lesarnia. Maximum absolute heights range from 600 to 780 m, relative heights from 150 to 180 m. In the relief there are low mountain ranges and ridges with elongated and domed peaks, extending in accordance with the general direction of the study area, ie from northwest to southeast. They are divided by numerous valleys of streams. The steepness of the slopes is mostly 2-7º, sometimes increasing to 15º. The flow valleys embedded in the andesites are characterized by a V-shaped structure and in tuffs by a U-shaped structure. The western and central parts of the Dudlibo-Omelyan morphostructure include andesites, andesite-dacites, andesite-basalts and their tuffs of

Antalivsky, Makovytsky, Matekivsky volcanic complexes superimposed on each other. The north-eastern part of the morphostructure is formed by dacites, rhyodacites, andesite-dacites, andesites and their tuffs of the bruise complex. The thickness of the complexes does not exceed 700 m. In the southern part of the morphostructure volcanic rocks are covered with deluvial and deluvial-proluvial deposits up to 10 m thick.

The morphostructure of Sinyak occupies the interfluve of Vyznytsia and Velyka Pina. In the northwest, its border runs along the watershed between the Lamovani Valley (left tributary of the Vyznytsia) and the Mlynsky Valley (left tributary of the Turia). In the south and south-east, the boundary of this fourth-order morphostructure runs along the line of the villages of Klenovets-Obava-Chinadiyevo and the valley of the Latorytsia river. Its length from north to south is about 24 km, from west to east - 17 km. In the western part of the morphostructure in the relief there are ridges of almost meridional extension: Tovsty, Shiyka and Plyshka (mountains Chalovisty, 860.0 m; Shyka, 702.9 m; Plyshka, 992.0 m; Obavsky Kamin, 979.2 m). The eastern part of the morphostructure is the Sinyak ridge with the Krugla (744.2 m), Dunauka (1018.8 m), Solochynsky Dil (943.0 m), Serednyi Verkh (980.7 m) and Zvesna (722.3 m) peaks. The central part of the morphostructure Sinyak is divided by the valley of the river Matekova and its numerous tributaries. The valley is well defined, narrow at the top with a V-shaped profile, and below the Fokova tract in the relief there is a floodplain. The slopes of the valley are convex, often straight, with a steepness of more than 25º. In the western part of the morphostructure, the absolute heights decrease to 500-680 m, and elongated and conical peaks stand out in the relief (mountains of Berdo, 678.4 m; and Shkitena, 530.3 m). The steepness of the slopes compared to the eastern part is also reduced and is 4-9º, and in the tract Yavornik does not exceed 3º. The shape of the slopes is mostly convex, convex-concave. In general, the morphostructure has the form of a stratovolcano, prepared by the erosion of watercourses. The morphostructure of Sinyak is formed by andesites and their tuffs of Antalivsky, Makovytsky, Matekivsky, Sinyatsky and Obavsky volcanic complexes, which were formed as a result of several eruptions that occurred at more or less equal intervals.

The Rozputy-Chinadiyev morphostructure of the fourth order is distinguished in the south-western part of the Antaliv-Synyatsky morphostructure of the third order. It occupies the interfluve of the Uzh and Latorica rivers. Its northern and north-eastern border runs along the line of the villages of Orikhovytsia – Yarok – Verkhne Solotvyno – Antalivtsi – Kiblyary – Lintsi – Patskanyovo – Rostovyatytsia – Mykulyntsi – Shchaslyve – Lesarnia – Klenovets – Obava – Chinadiyevo. The south-western border coincides with the border of the Chop-Mukachevo lowland. It is characterized by high-altitude accumulative-denudation relief. The maximum absolute heights of the morphostructure range from 400-560 m. The highest peaks are located in the central and eastern parts of the morphostructure: Zhornyna (543.4 m), Khudlivska (551.7 m). The structure of the morphostructure involves volcanic rocks of various volcanic complexes, which are sometimes covered with a thick crust of weathering of andesites and deluvial-proluvial deposits. The Rozputy-Chinadiyev morphostructure is characterized by smoothed outlines of ridge surfaces with a predominance of dome-shaped peaks and rather wide valleys of the main rivers with declining slopes. In fact, these valleys divide the Rozputy-Chinadiyev morphostructure into Rozputsky (Uzh and Tsygany interfluve), Strypo-Kholmetsky (Tsygany and Stara interfluve), Khudlyovo-Linska (interfluve of the Stara and its tributaries), Kuzmynska (Stara and Polyuy interfluve) and Zhornynska (the interfluve of the Polyuy and Vyznytsia rivers) and the Klynovets-Chinadiyev (interfluve of the Vyznytsia and Matekova rivers) morphostructures of the fifth order.

The Rozputy morphostructure is represented by a wide ridge with dome-shaped elongated peaks (m. Rozputy, 291.0 m). Its north-eastern border runs along the line of the villages of Orikhovytsia-Yarok. The south-western part of the morphostructure is strongly dissected by streams flowing into the Uzh river and the reclamation canals of the Chop-Mukachevo plain. Absolute heights up to 140 m decrease in the same direction. Convex and straight slopes with a steepness of 1-7º predominate.

The Strypa-Kholmetska morphostructure on the interfluve of the Tsygany and Stara rivers is distinguished by four ridges and a dome-shaped massif, which are strongly dissected by tributaries of the Tsygany and Stara rivers. The north-eastern border runs along the Strypa-Khudlyovo line. The maximum absolute heights are 330 m and gradually decrease to 195 m in the direction of the Chop-Mukachevo lowlands. An exception is the massif with dome-shaped peaks (301.0 m; 302.5 m) south of the village Hlyboke, which is composed of sub-intrusive bodies of acidic composition. For strands that stretch from north to south, elongated narrow surfaces, convex slopes with a steepness of 3-7º are characteristic. The domed massif is characterized by convex, convex-concave slopes with a steepness of 7-18º.

The Khudlovo-Linska morphostructure is represented by a ridge with a conical peak (551.7 m), stretching from northeast to southwest and a wide massif with elongated and domed peaks, which gradually decreases in the southern direction to the Chop-Mukachevo lowlands. A strand of the array separates the Lyn stream. The apical surfaces of the ridge are mostly elongated and wavy. North-western, southern and south-eastern slopes of the ridge are straight, steeply 5-18º. The slopes are dissected by a large number of ravines formed on yellow-gray loams.

For a wide massif located in the southern part of the morphostructure, lower absolute heights and steeper slopes are characteristic compared to the ridge. Absolute heights decrease from north to south from 270 m to 189 m, respectively. Apical surfaces are wide, bumpy. Convex slopes with a steepness of 2-7º predominate. The array is strongly divided by ravines, which are concentrated in the southern part. The morphostructure consists of andesites of the Antalivsky and Makovytsky complexes and sub-intrusive bodies of acidic composition (dacites), which form the apical surfaces. In the southern part of the morphostructure, the thickness of volcanic rocks decreases towards the Chop-Mukachevo lowland, while the thickness of quaternary sediments, represented by pebbles of ancient terraces, which are covered with clays and yellow-brown loams with a thickness of 2 to 20 m.

The fifth-order Kuzminska morphostructure occupies the interfluve of the Stara and Polyuy rivers. Its northern and northeastern border runs along the line of the villages of Lintsi-Patskanyovo-Rostovyatytsia-Mykulyntsi-Bobovyshche, and its southern line runs along the Polyuy valley. In relief it is expressed by low ridges elongated from north to south with wide, elongated and rounded peaks, which are strongly dissected by tributaries of the Stara and Polyuy. In the same direction, the absolute heights decrease from 340.4 m to 161.3 m. The relative heights are 120-180 m. The slopes of the strands are mostly convex, with a steepness of 2-5º, sometimes exceeding 7º. In the southern part of the morphostructure, below the villages of Kuzmino and Kopynovtsi, ravines up to 10 m wide and 2-3 m deep stand out well in the relief. The morphostructure is partially formed by andesites, andesite-basalts of Kuchavsky, Antalivsky and andesite-dacites of Synyatsky volcanic complexes, which are covered with pebbles of ancient terraces and a thick layer of deluvial and deluvial-proluvial deposits.

The Zhornynska morphostructure on the interfluve of the Polyuy and Vyznytsia rivers has the form of an elongated ridge from north to south with narrow, conical peaks (453.8 m; 567.0 m; m. Zhornyna, 543.4 m). Its northern border runs along the line of the villages of Bobovyshche – Ilkovytsia – Lesarnia, south-western and southern - along the line Ruske – Ivanivtsi – Klyachanovo and the valley of Latorytsia. The slopes of the ridge are strongly dissected by tributaries of Polyuy and Vyznytsia, as well as ravines formed in yellow-gray loams. Straight and concave slopes with a steepness of 5-15º prevail. The morphostructure consists of andesites, andesite-basalts, andesite-dacites of the Kuchavsky and Matekivsky complexes, which in the south-western part are covered with terrigenous deposits, pebbles of ancient terraces and deluvial-proluvial deposits.

The fifth-order Klenovets-Chinadiyevska morphostructure occupies the interfluve of the Vyznytsia and Matekova rivers. The northern border runs through the villages of Klenovets and Obava, and the southern border runs through the valleys of the Obava and Latorytsia rivers. The morphostructure has the form of a small massif, in places with dome-shaped peaks, strongly dissected by tributaries Vyznitsa, Obava and Matekova. The maximum absolute heights are characteristic of the north-eastern part and are 291.8 m. The slopes of the massif are mostly convex, with a steepness of 1-7º, although in the southern part of the morphostructure the steepness of the slopes reaches 17º. In the area of the villages of Obava and Klenovets, the relief features a large number of negative forms, represented by beams and ravines. The ravines are 15 m wide and 5 m deep. The morphostructure is formed by andesites, andesite-basalts, andesite-dacites of the Matekivsky and Sinyatsky volcanic complexes, in the southern part covered by alluvial deposits of the second terrace of Latorytsia and deluvial loams.

The morphostructure of Velykyi Dil, which is dominated by low-mountainous volcanic-denudation relief, occupies the interfluve of the Latoritsa and Borzhava rivers. Its geomorphological structure is similar to the structure of the Antaliv-Synyatskaya morphostructure. In the northwestern part there is the Borliovy Dil massif with the Dehmaniv peak (1017.6 m). Numerous branches diverge radially from it, separated from each other by deeply incised valleys of many streams. The largest massif in the northern and north-western directions is fixed by the peak of Kichera (737.2 m), the other is located between the two sources of Bystryy (over 600 m). In the southern direction it is a branch of the Kryvulya tract (822.7 m). The massif has the appearance of a well-preserved stratovolcano (Kravchuk 2008). Dominated by straight slopes, which in the lower part become concave. The steepness of the slopes average between 15 and 20º. To the south-east the Velykyi Dil ridge stretches, which is separated from the Borliov Dil massif by the valley of the Irshava river and the upper reaches of the Kvasny Stream (left tributary of the Dusynka river). The highest peaks are Shelelovsky Verkh (729.1 m), Zlobsky (832.1 m), Buzhora (1085.5 m, the highest peak of the Volcanic range), Kamin (957.2 m), Sinyak (1035.2 m), Bystra (1002.5 m). The north-western part of the ridge is divided by the Irshava river. On its left bank there is an arched ridge with the top of Kryvulya (591.3 m), which from the east, southeast is surrounded by domed massifs with the peaks of Smologovytsky Dil

(807.1 m), Martynsky Kamin (989.0 m), Berehovy Dil (926.3 m) and Yavir (717.0 m). The morphostructure of Velykyi Dil is formed by the superimposed deposits of the Kuchavsky (southwestern part), Matekivsky, Synyatsky, Obavsky, Martinsky, and Muzhorsky volcanic complexes. They are represented by andesites, andesite-basalts, their tuffs, lava breccias, tuffites and basalts. Within the morphostructure of the Velykyi Dil, which belongs to the third order, we distinguish three morphostructures of the fourth order: Borliovo, Buzhorsk and Khat.

The fourth-order Borliovo morphostructure is bounded on the northwest by the valley of the Latorica River, on the north and northeast by the valley of the Dusynka river, on the east by the upper Kvasny stream (a tributary of the Dusynka river) and the Irshava river valley, and on the southwest by a line of villages Olkhovytsia – Letsovytsia – Babichi – Klenovytsia – Zagattya. In the relief the morphostructure is expressed by the cone-shaped mountain massif Borliov Dil with the Dehmaniv peak (1017.6 m). The massif has a round shape with a diameter of about 10 km, which divides a large number of streams flowing into the rivers Latorytsia, Dusynka, Irshava. The streams are characterized by deeply incised valleys, in most of the slopes with a V-shaped structure. The upper and middle parts of the slopes are mostly straight, with a steepness of 15-30º. The lower part of the slopes is characterized by a concave profile, with a slope steepness of up to 8º. The southern slopes of the massif are elongated in the direction of the Kryvulya river valley, their steepness does not exceed 5º. The Borliovo morphostructure is composed of deposits of the Kuchavsky, Matekivsky, Synyatsiky, and Obavsky volcanic complexes. The Kuchavsky complex is formed by andesites, andesite-basalts, their tuffs, which occur in the basin of the Irshava river and in the south of the morphostructure. It is overlain by andesites, tuffites and lava breccias of the Matekivsky complex. Above the sediments of the Matekivsky complex in the central and eastern part of the morphostructure lie dacites, andesite-dacites, and their tuffs of the bruise complex. The Obavsky complex is represented by large porphyry andesites and andesite basalts, which form the apical part and the southern slopes of Dehmaniv.

The morphostructure Buzhora in the northwest is bounded by the upper reaches of the Kvasny stream (a tributary of the Dusynka river) and the Irshava river valley, in the north by the Dusynka river valley, in the northeast and southeast by the Borzhava river valley, and in the southwest by the Irshava river and Irshava basin. In its north-western part there is an arched ridge with the top of Kryvulya (591.3 m). It is characterized by elongated and rounded peaks, straight and convex slopes, which are strongly divided by the valleys of the rivers Irshava and Abranka. The steepness of the north-western slopes is over 25º. To the east and south-east of this ridge there is a domed massif with peaks Smologovytsky Dil (807.1 m), Martynsky Kamin (989.0 m), Berehovy Dil (926.3 m) and Yavir (717.0 m). The massif is strongly divided by the rivers Abranka, Chorna Irshava and their numerous tributaries. The apical surfaces of the massif are wide, domed. The south-western slopes of the massif are mostly concave, with a steepness of 7-18º. The northern slopes are characterized by a convex profile, steepness from 3º in the apical parts to 30º in the valley of the Irshava river.

The largest ridge of the morphostructure, Velykyi Dil, stretches from the Kvasny stream to the Borzhava river valley. In the north-west it is separated from the dome-shaped massif described above by the valley of the Irshava River, and in the west by the valley of the Ilnychka river. The ridge is fixed by the peaks Shelelovsky Verkh (729.1 m), Zlobsky (832.1 m), Buzhora (1085.5 m, the highest peak of the Volcanic ridge), Kamin (957.2 m), Sinyak (1035.2 m), Bystra (1002.5 m). The apical surfaces of the ridge are mostly narrow, elongated, conical. The northern and northeastern part of the ridge is divided by numerous left tributaries of the Dusynka river and the right tributaries of the Bystry and Borzhava rivers. In this area, the slopes are characterized by a complex structure: the upper parts of the slopes are straight, steepness over 25º, the middle and lower part is mostly concave-convex, steepness 7-15º. In the southern part of the morphostructure is the Irshava basin, which is dominated by hilly-plain dissected relief. It is composed of layers of clay with layers of sandstones, siltstones and lignites of the Ilnytsya world (Panon). In its south-western part there are clay deposits with layers of tuffs and tuffites of the Almashi and Lukiv Sarmatians. Floodplains and low floodplain terraces within the basin occupy large areas, and the basin can be considered as a separate morphostructure of lower order. The andesite basalts of the Kuchavsky, Matekivsky, Synyatsky, Martinsky and Buzhorsky volcanic complexes take part in the construction of the Buzhora morphostructure.

The south-western part of the interfluve of the Latorytsia and Borzhava rivers is occupied by the Khat morphostructure. From the northeast it is limited by the villages of Olkhovytsia-Babichi-Zagattya and the valley of the Irshava river, and from the south-west by the villages of Kuchava, Stanovo, Zavydovo, Negrovo, Ardanovo, and Siltse. The relief is represented by a ridge stretching from northwest to southeast. In this direction, the absolute heights recorded by the peaks of Velykyi Kamin (434.5 m), Velykyi Gorotan (407.6 m), and 260.5 m (near the village of Siltse) also decrease. The structure of the morphostructure is dominated by tuffs. Therefore, the tributaries of the Irshava, Borzhava and Latoritsa rivers divide the ridge into separate spurs of different directions, ending mainly in small domed massifs (242.6 m, near the village of Bystritsa). The north-eastern slopes of the ridge are gentle, steeply 3-7º and more dissected. South-western slopes are convex-concave, steepness in the apical part up to 15º, and in the middle and lower - 3-5º.

The morphostructure Khat consists the deposits of Kuchavsky, Matekivsky and Obavsky volcanic complexes. In the north-western part of the morphostructure from the village Kuchava to the village of Negrovo there is a layer of andesite tuffs with a thickness of about 56 m from the Kuchavsky complex. The complex is covered with tuffs of andesite, andesite-basalt of the Matekivsky complex, which are common between the villages of Dilok and Silce. Sediments of the Obavsky complex are distributed on the south-western slope of the ridge, represented by erosive remnants of andesite-basalt up to 10-25 m thick.

The Morphostructure Tupy occupies the interfluve of the Borzhava and Tisza rivers, its length is 16-18 km. The morphostructure is characterized by low-mountainous volcanic-denudation relief, which is represented by a meridional ridge with well-fixed peaks Maly Klobuk (568.2 m), Grabova (782.5 m), Tupy (878.5 m), Doschata (761.3 m), Tovsta (819.2 m), Irosla (598.6 m). Its north-eastern border runs along the valleys of the Dovhy and Lipche rivers, and its western border runs along the lines of the villages of Velykyi Rakovets-Vertep-Rokosovo. The ridge divides a large number of tributaries of the Borzhava and Tisza rivers, forming elongated massifs with cone-shaped and domed tops. The largest of them in the eastern, western and north-western directions are recorded by the peaks of Ilyka (758.2 m), Rorond-Tete (554.0 m), Kititsa (841.0 m), Yuritsa (630.2 m). The average absolute heights of the Tupy ridge are 100-150 m lower than those of the Velykyi Dil ridge. Apical surfaces are mostly narrow, wavy and rounded. The south-eastern slopes of the ridge, which are divided by tributaries of the Tisza River, are mostly straight with a steepness of more than 20º. The western slopes are characterized mostly by a convex profile, steepness of 15-20º at the top and 2-6º at the foot. In the interfluve of Lipovets and Lipcha there is a decrease in absolute heights from 463.2 m to 294.4 m, and the steepness of the slopes does not exceed 11º.

Sediments of Kuchavsky, Matekivsky, Synyatsky and Obavsky volcanic complexes take part in the construction of the morphostructure. Andesites, andesite-basalts and their tuffs of the Kuchavsky complex lie in the southern part of the morphostructure near the "Khust Gate". They are covered with andesites, lava breccias, tuffs and tuffites of the Matekivsky complex, which are distributed throughout the morphostructure Tupiy. The rocks of the Synyatsky complex form two layers of sediments. The lower stratum, which is composed of tuffs of rhyolites, rhyodacites, andesito-dacites up to 240 m thick, lies directly on the sediments of the Matekivsky complex. The upper stratum is represented by andesite-dacites with low-thickness strata (up to 2-3 m) of psephytic tuffs, common in the southwestern part of the morphostructure. Andesite-basalts and basalts of the Obavsky complex are formed on the rocks of the Matekivsky and Synyatsky complexes, which form the top parts of the Tovsty, Kytytsia and Tupy mountains (Matskiv et al. 1996).

The morphostructure Oash stretches from the valley of the Tisza River to the border with Romania. The relief is represented by the northern part of the Gutyn ridge and its north-eastern slopes, which are divided by the left tributaries of the Tisza River into separate spurs with cone-shaped and dome-shaped peaks. The northern part of the ridge is fixed by dome-shaped peaks of Sarget (394.7 m), Kamin (347.1 m), Krzhivsky Verkh (390.8 m), Pinteva Studnya (467.7 m), Bagno (602.3 m) and Frasin 826.4 m). The northern and north-eastern slopes to the Tisza River valley are short, mostly straight and convex, with a steepness of 15-25º. The southern and southwestern slopes are concave and longer, with a steepness of up to 11º. The central part of the ridge is formed by andesite-basalts, and on the periphery - volcanic-conglomerates and tuff gravelites of the Matekivsky volcanic complex, which are covered with dacites, andesitic-dacites of the Synyatsky complex. The apical part of the ridge is formed by andesite-basalts, basalts and their tuffs of the Buzhorsky complex (Matskiv et al. 1984, Matskiv et al. 1996; Matskiv et al. 2001; Prikhodko M., Titov E. et al. 1980). Intrusive peaks Kruglyak (520.1 m), Maly Cherepovets (456.3 m), Shayan (440.0 m), Gostra (577.3 m), Fekete-Khed (769.4 m), Chorny Bor (699.3 m), Var-Khed (589.6 m) and Lysiy Kholm (665.3 m) can be traced between the villages of Velyatino and Yablunivka on the spurs of the Hutyn ridge. The slopes of the spurs are mostly concave, with a steepness of up to 15 °, approaching the floodplain of the Tisza River. The structure of the peaks mainly involves panno-pont deposits, which are represented by andesitic porphyrites, diorites and diorite-porphyrites (Matskiv et al. 2001).

The Beregovo morphostructure of the third order with hilly volcanic-denudation relief is bounded on the west and south by the Verke Canal, on the southeast by the Borzhava river, and on the north and east by the Zatyshne-Kidosh-Velyki Berehy-Kvaso villages. In relief it is expressed by hills with maximum absolute heights of 298.5 m and 365.7 m. The length of the mountain range from northwest to southeast is about 13 km. The apical surfaces are domed, wide and wavy. The top parts of the slopes are mostly straight, steeply 7-13º. For the middle and lower parts of the slopes is characterized mainly by a concave profile, steepness 2-7º. The slopes are divided by numerous ravines and beams, which end in powerful cones of removal of proluvial material. The Beregovo hills are the volcanic remnants of Sarmatian volcanoes, which are covered by thick sedimentary strata of Neogene and Quaternary sediments. They are composed of deposits of the Velykodobronsky and Barkasivsky volcanic complexes. The Velykodobronsky complex is located in the eastern part of the Berehovo hills. It is formed by andesites and their tuffs up to 400 m thick, which lie in the lower part of the mountain range (Matskiv et al. 1996).

Barkasivsky complex is the most common. With a stratigraphic break, it is deposited on the deposits of the Velykobronsky complex and sedimentary deposits of badenium. The lower and middle part of the complex is formed by rhyolite tuffs with layers of terrigenous rocks up to 950 m thick. In the upper part there are domes and streams of rhyolites, perlite, their lava breccias, tuffs and tuffs up to 350 m thick (Fishkin 1954; Matskiv et al. 2001).

The Kosino-Bigan morphostructure of the third order is located between the villages of Kosino and Velyka Bigan. The relief is represented by dome-shaped volcanic remains with relative heights of 100–120 m. In its northern part near the village Zapson is a volcanic remnant measuring 1.6 × 1.2 km with a maximum absolute height of 207 m. The slopes of the hill are convex, weakly dissected, with a steepness of up to 10º.

To the south of the village Zapson is a volcanic massif measuring 2 × 3 km, which is represented by domed, wide peaks with absolute heights of 223.0 and 200.0 m (m. Tipet). The eastern and southern slopes of the massif are straight, steeper than 15º. Western slopes are concave, moderately dissected, steeply 3-10º. To the east of this massif (near the village of Velyka Bigan) there are two volcanic remains, elongated in the south-eastern direction, which are fixed by the peak of Biganska (192.0 m) and the absolute mark of 171.6 m. The andesites of the Velykodobronsky complex, which are covered by thick strata of rhyolite tuffs of the Barkasivsky complex, take part in the construction of the morphostructure.

The Shalanky morphostructure of the third order is located between the villages of Shalanky and Velyki Komyaty. The relief is represented by a small (2.5 × 3.5 km) volcanic massif with the highest conical peak Shalansky-Helmets (368.6 m). The massif is characterized by short, straight and convex northern slopes up to 20º, which approach the channel of the Borzhava river. The western, southern and eastern slopes are concave, steep up to 12º, strongly dissected by ravines, the depth of which reaches 5 m. The morphostructure is composed mainly of layers of bipyroxene andesites and their tuffs with a thickness of 580 m of the Chicoshsky volcanic complex (Matskiv 1996).

The morphostructure Chorna Hora is located to the east of Vynohradiv. Its northern and northeastern border runs along the valley of the Salva stream and the line of the willage Mala Komyata, and the eastern one - along the Tisza riverbed. The relief is expressed by an elliptical mountain, elongated in the meridional direction, 4.5 km long and 3-3.5 km wide. It is fixed by a conical narrow peak of Chorna Hora (565.0 m). The slopes of the mountain are mostly straight, steeply 13-18º. The exception is the eastern part of the mountain, which is washed away by the Tisza River, the steepness of the slopes here is more than 25º. This morphostructure is formed by andesites, andesite-basalts, dacites, rhyolites and their tuffs of the Matekivsky and Sinyatsky volcanic complexes (Matskiv 1984).

Conclusions

Taking into account the differences in the spatial arrangement of tectonic elements and volcanic structures as well as their emergnece in the relief, Vygorlat-Gutyn and Mukachevo morphostructures of the second order are divided into morphostructures of the third order. Structural and lithological features have determined the specific features of their relief, which are expressed by narrow ridges with dome and conical tops.

The highest absolute altitudes within the study area are characteristic of the Antaliv-Synyatsky and Velykodilsky massifs (900-1,085 m). Differences in the relief of the north-western and south-eastern parts of the Vygorlat-Hutyn ridge are well traced, which is due to the lithological composition of the rocks. The ridges, which are dominated by andesites, are characterized by narrow conical apical surfaces, in contrast to the dome-shaped ridges and massifs composed of dacite intrusions. In the south-eastern part of the volcanic ridge and its spurs are less massive, their absolute heights decrease, there is a symmetry of the slopes.

It was found that the most important morphosculptures that form the relief of the study area are river valleys and leveling surfaces. The river valleys, which cut deep into the andesites, are characterized by a V-shaped cross-section profile, which causes a significant steepness of their slopes. At the exit of river valleys to areas that are composed mostly of tuffs, the valleys become wider and trough-like, with a general decrease in the steepness of the slopes.

The results of the study can be used in assessing the terrain for engineering, environmental and recreational purposes. Theoretical and practical developments can be used in complex geographical research and compiling a general geomorphological map of Ukraine. The obtained quantitative indicators of the state of division of the territory can serve as an information base during the planning and design of anti-erosion and anti-flood measures within the Transcarpathian region.

Funding

This research received no external funding.

Author contribution

Conceptualization, methodology, writing – original draft, Mykhailo Mykyta; writing - review & editing, validation, Maryana Salyuk, Roman Slavik and Mykola Karabiniuk; data curation, Vasyl Leta. All authors have read and agreed to the published.

Conflicts of Interest

The authors declare no conflict of interest.

References

Alfer'ev, G., (1968). Some considerations about the young movements of the Carpathians. Tr. Lviv. geol. ob-va, Ser. geol. 1: 87-106 (in Russian)

Dziuba, A., (2000). Methods of preparation of raster cartographic materials. GIS Association Information Bulletin 2 (24): 19-20 (in Russian)

Fishkin, M., (1954). About Liparite domes of the Beregovsky district of the Transcarpathian region. Bull. volcano. stations 23: 54-63 (in Russian)

Gerenchuk, K., (1981). Nature of the Transcarpathian region. High school, Lviv (in Ukrainian)

Hofstein, I., (1995). Geomorphological sketch of the Ukrainian Carpathians. Science. opinion, Kyiv (in Russian)

Kamanin, L., Ivanova, G., (1954). On the geomorphology of the foothills of southwestern Transcarpathia. Tr. Institute of Geography of the USSR Academy of Sciences 62: 124-158 (in Russian)

Karpenko, N., (2009). Master's seminar for geomorphologists. Educational and methodical manual. Published. center of LNU I. Franko, Lviv (in Ukrainian)

Kostyuk, V., (1961). Geological and petrographic sketch of the Carpathian magmatism. Published by the Academy of Sciences of the USSR, Kyiv (in Russian)

Kravchuk, Y., (2008). Geomorphological regionalization of the volcanic ridge of the Ukrainian Carpathians. Problems of geomorphology and paleogeography of the Ukrainian Carpathians and adjacent territories: Proceedings of the third international seminar: 3-20 (in Ukrainian)

Maleev, E., (1964). Neogene volcanism of Transcarpathia. Science, Moscow (in Russian)

Matskiv, B., Koval'ov, Yu., Pukach, B., Vorobkanich, V., (2001). State Geological Map of Ukraine. Carpathian series. Sheets M-34-XXIX (Snina), M-34-XXXV (Uzhhorod), L-34-V (Satu Mare) and Explanatory note. Kyiv (in Ukrainian)

Matskiv, B., Koval'ov, Yu., Voloshin, B. et al., (1984). Report on deep geological mapping within sheets M-34-133-B, G; L-35-I-A, B for 1980-1984 (Rakhiv ore district). f. ZGRE, Beregovo (in Russian)

Matskiv, B., Zobkov, O., Koval'ov, Yu. et al., (1996). Report on geological research of the territory of scale 1: 200000 tablets M-34-XXIX, M-34.-XXXV, L-34-V (Uzhgorod group of letters). Berehovo (in Russian)

Merlich, B., Spitkovskaya, S., (1974). Deep faults, Neogene magmatism and mineralization of Transcarpathia. High school, Lviv (in Russian)

Palienko, V., Sokolovsky, I., (1979). Experience in classifying the morphostructures of the Ukrainian Carpathians. Physical geography and geomorphology 21: 23-31 (in Russian)

Prikhodko, M., Titov, E. et al., (1980). Report on additional study of the geological structure of previously photographed areas on a scale of 1:50000 of the territory sheets M-34-131-A, V, B (Buzhora group of sheets for 1977-1980). f. ZGRE, Lviv (in Ukrainian)

Sobolev, V., Vartanova, N., Gorbachevskaya, O., (1947). Petrography of Neogene volcanic rocks of the Uzhgorod-Khust Range. Tr. Lviv. geol. about-va, petrographer. series 1: 3-71 (in Russian)

Yermakov, N., (1948). On the stratigraphy of Neogene sediments of Soviet Transcarpathia. Tr. Lviv. geol. about. Ser. geol. 1: 26-42 (in Russian).

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **109**-**122**
http://dx.doi.org/**10.5775/fg.2022.175.d**

Features of the morphology and dynamics of the shallow-island part of the Dolgaya Spit (the Sea of Azov)

Viacheslav KRYLENKO[1], Marina KRYLENKO[1,*]

[1] Shirshov Institute of Oceanology, Russian Academy of Sciences, 117997, 36 Nakhimovskiy pr., Moscow, Russia
* *Corresponding author*: krylenko@mail.ru

Received on 20-04-2022, reviewed on 26-09-2022, accepted on 10-10-2022

Abstract

The relief of large coastal accumulative bodies, including cuspate spits, is an important subject in scientific and applied research. A characteristic feature of similar accumulative bodies is a shallow underwater part. The aim of this work is to study the shallow-island part structure of the Dolgaya Spit (the Sea of Azov) and to identify the natural mechanism that determines both the variability of accumulative body over short time intervals and the high stability of the geosystem as a whole. Digital elevation models (DEM) for the studied area were built on the basis of remote sensing data (Sentinel-2). It is established that the length of the shallow-island part is about 20 km. There are shelly shoals and islands with a complex configuration and relief. Sea level, the wind-wave regimes and the sediment load are the main factors that determine the dynamic equilibrium of the shallow-island part of the Dolgaya Spit and its relief. The Dolgaya Spit has distinctive features of a free accumulative body influenced by longshore sediment flow. The configuration of its surface part is characteristic of many cuspate spits formed by two sediment streams. But the shallow-island part develops under the influence of alternating transverse movements of water masses and waves from opposite sectors. The coexistence of signs of the near-shore bar and cuspate spit provides grounds for classifying the Dolgaya Spit not as a cuspate accumulative body (in particular as Azov-type spit) but as a separate type developing under joint action of transverse and longshore sediment flows.

Keywords: *submarine relief, spit, coastal dynamics, remote sensing, Sea of Azov*

Rezumat. Caracteristici ale morfologiei și dinamicii insulei superficiale a Spitului Dolgaya (Marea Azov)

Relieful depunerilor sedimentare marine, ca de exemplu bancurile de nisip submerse, este un subiect important pentru cercetarea științifică și cu caracter aplicativ. O trăsătură de bază a acestor depunri sedimentare este dată de existența unor adâncimi mai mici. Lucrarea de față își propune să analizeze structura de mică adâncime generată de spitul Dolgaya (Marea Azov) și să identifice mecanismele naturale care determină atât variabilitatea acumulărilor pe o perioadă scurtă de timp și stabilitatea mare a gesosistemului ca întreg. Modelele digitale de elevație pentru zona de studiu au fost realizate cu ajutorul teledetecției (Sentinel-2). S-a stabilit că lungimea banculuisubmers este de aproape 20 km. Există și bancuri de cochilii și insule cu o configurație și relief complex. Nivelul mării, regimul vânturilor și al valurilor, precum și încărcătura de sedimente sunt principalii factori care determină atât echilibrul dinamic al insulei superficiale a Spitului Dolgaya și al reliefului acesteia. Spitul Dolgaya are caracteristicile distinctive ale unui corp e acumulare influențat de transportul sedimentor în lungul țărmului. Configurația părții exondate este marcată de prezența bancurilor de nisip formate de doi curenți de nisip. Totuși, partea mai puțin adâncă se dezvoltă sub influența mișcărilor transversale alternante ale maselor de apă și valurlor din sectoare diferite. Datorită prezenței aluviunilor în apropierea țărmurilor, precum și a bancului submers, putem considera că Spitul Dolgya nu este o corp de acumulare (de tipul spiturilor Azov), ci mai degrabă este un tip separat, care se dezvoltă sub acțiunea conjugată a depunerilor de sedimente atât transversal, cât și în lungul țărmului.

Cuvinte-cheie: *relief submers, spit, dinamica țărmului, teledetecție, Marea Azov*

Introduction

The relief of large marine accumulative bodies is an important subject of study in scientific and applied research. High variability is common to most natural geosystems, in particular to coastal accumulative ones. Alteration of one or more components of geosystems usually results in a transformation of the accumulative body, but not in the degradation of the whole geosystem. However, if natural changes in external conditions exceed a certain limit, or are enhanced by anthropogenic influences, irreversible destruction of the geosystem can occur. The study of the landform morphology and dynamics of marine coastal accumulative bodies makes it possible to identify the mechanisms of their formation and evolution and to assess composition and significance of acting factors.

Geosystems of accumulative bodies, known as cuspate spits, are peculiar and complex (Rosen, 1975, Zenkovich, 1959). Cuspate spits are one of a family of shoreline reorientation features that includes cusplike structures, giant cusps, looped spits, and cuspate forelands (Rosen, 1982). These accumulative bodies are formed in stretches of coastline where two sediment streams meet. Examples include: Point Pelee peninsula (Lake Erie); cuspate foreland at northeast end of Graham Island (Pacific coast of Canada); cuspate spits of St. Lawrence Island (USA); Cape Dungeness (southern coast of Britain); Cape Kolka (the Baltic Sea); Cape Henlopen (Atlantic coast of the USA); the Bakalskaya Spit (the Black Sea). Some of these accumulative bodies were distinguished into a special type and received the name of Azov-type spits. These include the Belosarayskaya Spit and the Obitochnaya Spit (the Sea of Azov) (Zenkovich, 1967, Fisher, 1955, Kosyan, Krylenko, 2019, Price, Wilson, 1956). Many active hydrological and other factors determine the complex lithodynamic regime of cuspate spits, and, as a result, high variability in time and space. At the same time, cuspate spit geosystems often show high stability, persisting over long periods of time. Most of these accumulative bodies are specially protected areas. This once again points to the complexity and uniqueness of these natural sites.

The object of the present study is the geosystem of an accumulative body of the Sea of Azov – the Dolgaya Spit (Fig. 1). The aim of our research is to discover features of the structure of the shallow-island part of the Dolgaya Spit and to identify the natural mechanism that determines both the variability of the accumulative body over short time intervals and the high stability of the geosystem as a whole. Based on the obtained up-to-date information on the structure and dynamics of the shallow-island part of the Dolgaya Spit, supplemented by historical and literary data, analysis of the regularities of the structure and evolution of this natural site has been carried out.

Fig. 1: Geographical location of the Dolgaya Spit

Characteristics of the development of the accumulative geosystem of the Dolgaya Spit

The Sea of Azov is one of the smallest on the planet and is situated in Western part of Europe. The length of the shores of the Azov Sea in 2018 amounted to 3430 km, its area – to 40 570 km^2 (Krylenko, Krylenko, Aleynikov, 2019). A feature of the modern dynamics of the shores of the Sea of Azov is predominance of erosion processes. Not only indigenous shores are subject to erosion, but also accumulative bodies such as spits, sandbars of lagoons and estuaries (Kosyan, Krylenko, 2019). The Yeysk Peninsula is washed by the waters of the Sea of Azov and the Taganrog Bay. Sand-shell accumulative bodies such as the Yeysk spit, the Dolgaya Spit and the Kamyshevatsk Spit adjoin the peninsula (Zenkovich, 1958) (Fig. 1).

Fluctuations in the level of the Sea of Azov during the Holocene repeatedly led to transformation of the accumulative bodies at the NW end of the Yeysk Peninsula. Before the Phanagoria regression (≈ 3,000 years ago), the sea level was close to that of present days. During that period, there was probably an accumulative body, close in lithodynamic regime and structure to the present-day Dolgaya Spit (Artyukhin, 1987). During the Phanagorian regression, the sea level lowered, on average, by 5 m in comparison with that of the present day (Matishov and Polshin, 2019). Due to the decrease in the sea level the influence of runoff currents in the Taganrog Bay increased. The accumulative body of the Paleo-Dolgaya Spit was almost completely eroded (except for the accumulative terrace along the original coast). The washed out material was redeposited in the direction of the resulting direction of the sediment flow (to the SW), determined by prevailing SW waves and runoff currents of the Don at that time. During subsequent transgression, the influence of W and SW disturbances increased. From this point on, the resulting direction of the sediment flow was directed to NW. Approximately 2,500 years ago, two small curved spits arose at the projections of the original shore, growing towards each other. About 1-1,200 years ago, these spits joined each other and later developed together, forming the accumulative body of the Dolgaya Spit as a cuspate spit.

The image of the present position of the Dolgaya Spit appeared on maps of the Sea of Azov in the 14th century (Fig. 2). Characteristically, all maps, even the oldest ones, show the Dolgaya Spit as a chain of islands. A detailed map of the Taganrog Bay by Peter Bergman (1702) shows the contours of underwater and above-water accumulative bodies of the Dolgaya Spit (Fig. 3) with measured depths. In (Budischev, 1808) there is information about the Dolgaya Spit and its submarine shoal: "The spit extends from the Obryv Cape to the NW – at first as an external sandy spit 11.64 km long, then it is continued for 8.45 km by a chain of small islands. The spit and the islands are surrounded by a narrow shoal, no more than 2.4 km wide and 26.4 km long, with a tongue bent to the north. Elevations and depressions are marked along the longitudinal axis of the shoal. The Sailing Directions of the Sea of Azov (Sukhomlin, 1854) contains the following information about the Dolgaya Spit: "The Doldaya Spit is 0.5 m wide and stretches from the Obryv Cape to the NW for 15.74 km. Together with occasionally formed islands the underwater extension of the Dolgaya Spit, stretching 9.3 km to the NW of the surface part, forms a long shoal 2.8 km wide". The sailing directions are supplemented by a map of the Sea of Azov by E.P. Manganari (Papacoma, 2020), a remarkably accurate representation of the coastal configuration and the submarine relief (Fig. 4).

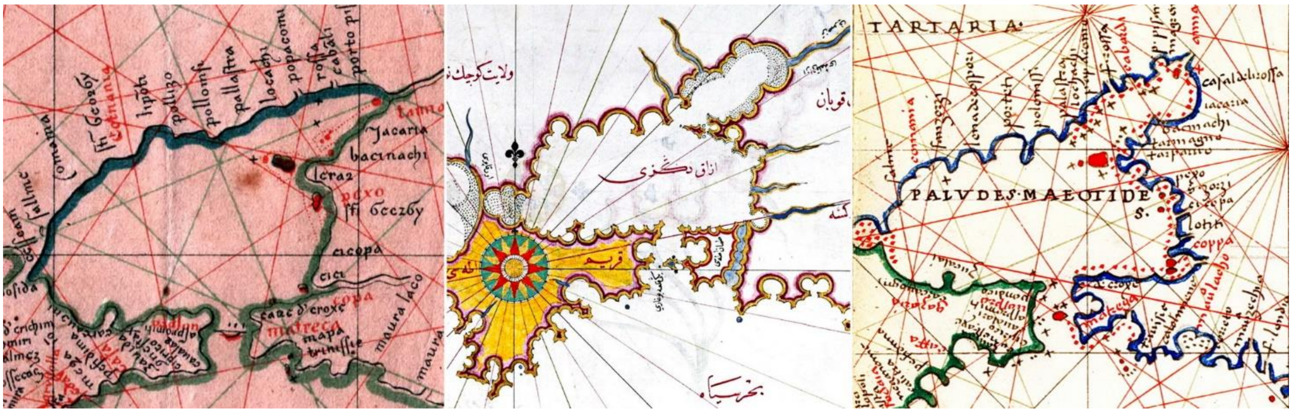


Fig. 2: The Dolgaya Spit on ancient maps: the portolan by Petro Vesconte (1318) on the left; a map in the atlas by Piri Reis (1525) in the centre, and the portolan by Battista Agnese (1540) on the right (Papacoma, 2020)

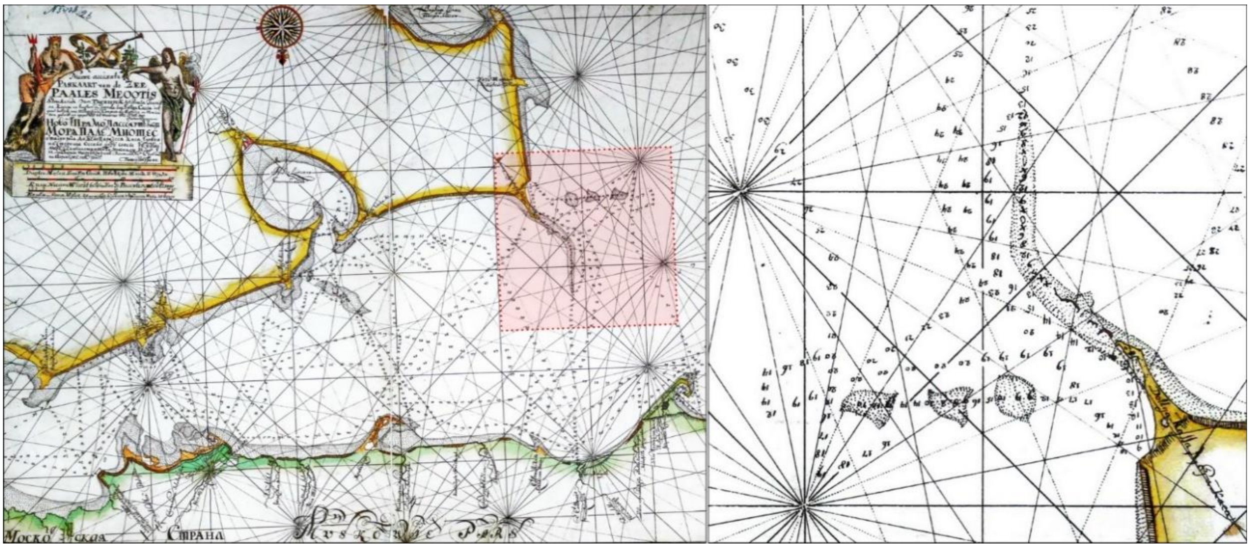


Fig. 3: Map of the Taganrog Bay by Peter Bergman 1702 (south on top). On the right: fragment with an image of the Dolgaya Spit (north on top) (Papacoma, 2020)

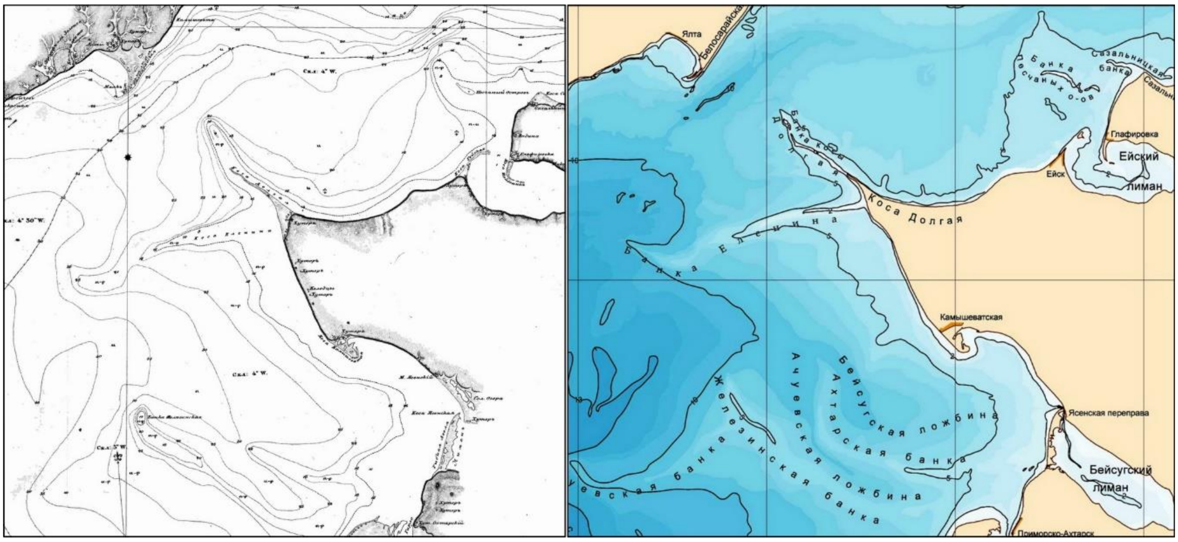


Fig. 4: Area of the Dolgaya Spit on a fragment of the map of the Sea of Azov by E.P. Manganari (1833) – on the left (Papacoma, 2020). Modern bathymetric map – on the right (Matishov et al., 2006)

Analysis of historical maps shows that the Dolgaya Spit's geosystem has been highly stable over the centuries. This accumulative body retains its structure: it consists of an above-water part (in a form of a cuspate spit), islands and shoals. During the development of the accumulative body of the Dolgaya Spit, the length of the above-water part of the spit periodically increased along the axis of the underwater shoal. At other times, on the contrary, the above-water part eroded or fragmented into a chain of more or less extended islands. As far as available maps show, the chain of the islands has never been connected into a single accumulative body. Over the last 150 years, the maximum length of the surface part (14 km) was observed in the 1940s and 1950s (Mamykina, and Khrustalev, 1980; Khrustalev, Scherbakov, 1974, Matishov, 2020). The comparison of maps from 1702 and 1833 with modern maps shows that the longitudinal axis of the underwater part and islands of the Dolgaya Spit geosystem is gradually shifting to the SW.

From the side of the Taganrog Bay and the open Sea of Azov, the Dolgaya Spit adjoins a abrasion shore composed of loess-like loams. The cliffs are 5-10 m high (Fig. 5) and the shore is eroding and receding at an average rate of 1-1.5 m per year (Kosyan and Krylenko. 2019).

Fig. 5: Abrasive shores at the root of the Dolgaya Spit: on the left – the Taganrog Bay (NE); on the right – the open Sea of Azov (SW)

The modern accumulative body of the Dolgaya Spit was formed mainly due to material of biogenic origin (shell) coming from the seabed. Abrasion products played some role in the initial stage of spit formation, but now the role of the biogenic source is much greater. The sediment of the Dolgaya Spit is dominated by shells: the sediment of the distal part and the shoal contain over 80% of the *Cerastoderma glaucum* clam shells, while that of the islands contains 90-95%. (Bespalova, 2007; Matishov, 2020).

Until the middle of the 20th century, the Dolgaya Spit was unaffected by human activity and developed exclusively under the influence of natural factors, after which the spit and underwater shoal were subjected to intensive shell mining. Y.V. Artyukhin estimates that a total of up to 4 million m3 of material was extracted from the accumulative body of the Dolgaya Spit (Artyukhin et al., 2015). From this point on, erosion processes at the tip of the Dolgaya Spit started to occur (Artyukhin, 1987), while the near-root part of the spit was generally stable (Fig. 6). In the 1990s, gullies formed in the spit (Bespalova, 2007) and it divided into a main part adjacent to the original shore and a shallow island part (Fig. 6). In subsequent years, the shallow island part of the Dolgaya Spit was mostly a chain of long (2 km or more) narrow islands extending along the axis of the bank. The overall length and relative position of the islands were constantly changing.

On 24 September 2014, a SW storm lasting more than a day, accompanied by a surge, destroyed the distal of the main part of the spit and all the islands. Since then, the Dolgaya Spit geosystem has been represented by a relatively stable near-shore part and an extremely dynamic submarine shoal, along the axis of which islands have started to form again since 2016 (Krylenko, Krylenko, 2017).

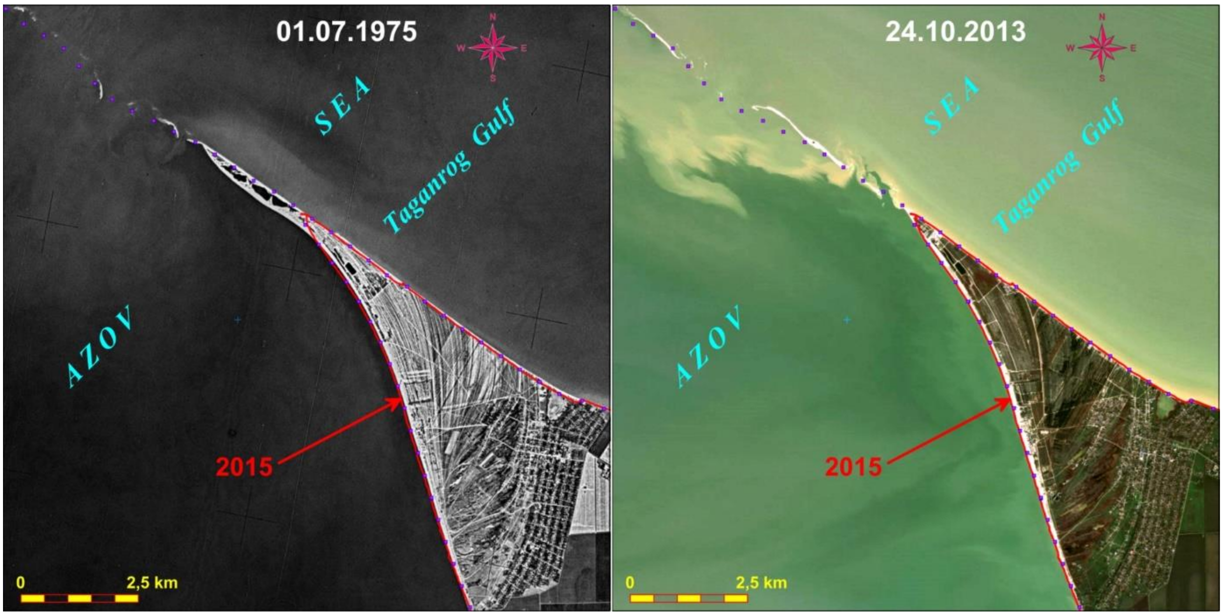


Fig. 6: Variability of the Dolgaya Spit: on the left – 1975, on the right – 2013. The red line marks the shoreline contour in 2015, following the erosion of the distal part and islands by the storm on 24.09.2014

Methodology

A characteristic feature of the Dolgaya Spit geosystem, like that of many other accumulative coastal bodies, is an extensive shallow underwater part. It is usually the most dynamic and variable part of the accumulative body, and the most difficult to study, as there are many methods for studying the surface relief, while the set of methods for studying the underwater relief is much smaller.

For a long time, underwater survey methods involved only direct measurements. Traditional bathymetric survey of water areas requires large material and time costs. In shallow areas, where both high detail of the terrain and its greatest variability are observed, bathymetric survey from the shipboard is often difficult or impossible. When studying underwater relief in the coastal zone, field measurements are usually conducted only along a small number of transverse and longitudal profiles. This is usually insufficient for identifying microforms of relief and studying its dynamics (Krylenko and Krylenko, 2018).

With the development of aviation and space industry, remote sensing methods dominated the study of underwater relief. The appearance of remote sensing satellites equipped with high-and medium-resolution spectrometers to detect radiation in a large number of spectral channels opened up new opportunities for the study of underwater relief in the depth range of 0-25 m. To date, a number of scientific studies and developed algorithms for calculating water depths using remotely sensed data are available (Chybicki, 2017, Hedley et al, 2005, Krylenko et al., 2019, Lyzenga, Malinas, Tanis, 2006). In this work, two algorithms were used to generate depth maps: Stumpf (2003) and Lyzenga (2006).

The waters of the Sea of Azov are characterized by increased turbidity associated with storms, biological processes, river runoff. According to the classification provided by the EOMAP Satellite Derived Bathymetry web service, the Sea of Azov belongs to turbid waters, with potentially possible depth for calculations of 5-10 m. There is no up-to-date information on the parameters of the water masses and bottom sediment for the entire study area. According to comparative testing (Zimin et al., 2018), both methods gave satisfactory results when generating depth maps from remotely sensed data for the Baltic, White and Black Seas with similar conditions (Chybicki, 2017, Traganos et al., 2018).

Sentinel-2, processing level 2A (Sentinel Online, 2020) images were used as input data. At the first stage, visual analysis of the available images was made. The criteria for selection were that the following conditions were met: no clouds over the study area, no strong waves, no surface film, minimal area of high turbidity zones. Unfortunately, there are extremely few images suitable for processing. The following images were used to map the underwater terrain: S2B_20180921_082959_109_37TCM; S2B_20180921_082959_117_37TDM; S2B_2019-10-16_121728_37TCM and S2B_2019-10-16_121728_37TDM

Pre-processing of images included correction of sun glare and creation of a mask of the water surface.

Hedley (2005) algorithm was used for the correction of sun glare. To eliminate sun glare, the algorithm uses the correlation between the visible (RED) and near infrared channel NIR.

The water surface mask was calculated using the formula of normalized difference water index: NDWI = (GREEN - NIR)/(GREEN + NIR). The resulting raster values are divided into two classes: water and land. The processed smoothed raster was converted into a polygonal vector object class.

Digital elevation models (DEM) were constructed for the study area with water depths up to 7 m (Fig. 7). Software implementation of depth mapping was performed using certified software ScanEx Image Processor. We used Blue (b02) and Green (b03) channels to obtain bathymetric information using the Stumpf (2003) method and Blue (b02), Green (b03) and Red (b04) channels when using the Lyzenga (2006) method. Calculation of natural logarithms (Stumpf, Lyzenga), coefficients of multiple regression (Lyzenga) and linear regression coefficients relative to the reference depth maps was conducted in the Scanex Image Processor. Nautical charts and data from direct acoustic bathymetric measurements were used as a reference map. The resulting accuracy in determining relative elevations and planned positions of individual underwater landforms is sufficient to make qualitative and quantitative assessments of transformation and planned displacement of hydrogenous forms.

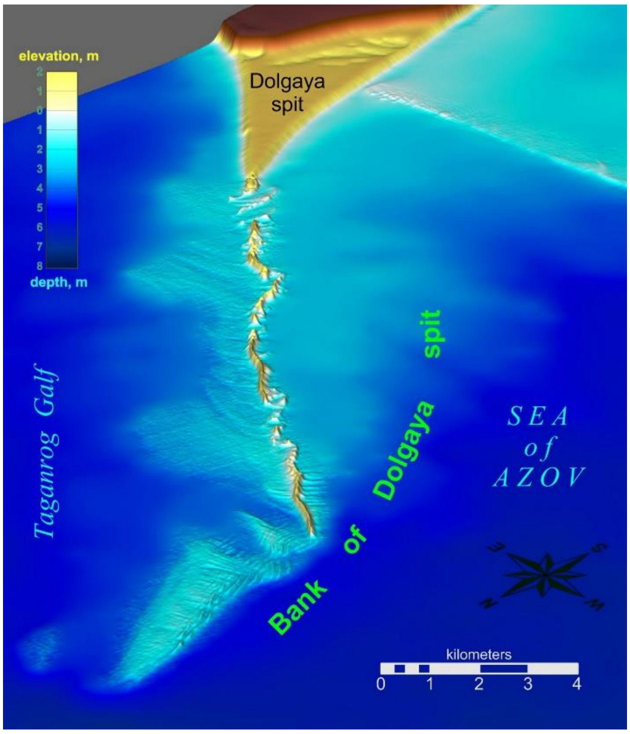


Fig. 7: 3D elevation model of the Dolgaya Spit geosystem (created from Sentinel-2 image, 16.10.2019)

Results and discussion

Structure of the shallow-island part of the Dolgaya Spit geosystem

The length of the shallow-island part is about 20 km. To describe the relief of the shallow-island part of the Dolgaya Spit geosystem, it is reasonable to distinguish between 'islands' – positive submarine or sometimes projecting over the water landforms outlined by a 1 m isobath and sometimes projecting above the water surface (Fig. 8, 9), 'shoals' – outlined by a 3 m isobath, and 'base' – outlined by a 5 m isobath.

The minimum width of the base (1.5 km) is found along the NE coast of the Dolgaya Spit, where it passes into the submarine flat-bottom land of the Taganrog Bay without pronounced boundaries. This indicates the longshore character of sediment migration in this area and the absence of transverse flow of sediment from the shore. D1 profile has a total base width of about 10 km (Fig. 8, 9). The total base width of the D4 profile is 8 km and that of D6 profile – 6 km. Near D7 profile, the base width decreases sharply to 3 km and its orientation and cross-section also change sharply (by 30-40°).

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December 2022**), pp. **109**-**122**
http://dx.doi.org/**10.5775/fg.2022.175.d**

In general, the relief of the base is even but has a few distinctive elements. In sections D1-D7 extensive plumes of sediment directed into the Taganrog Bay can be traced 2-2.5 km NE of the axis of the shallow-island area. The orientation of the plumes indicates that the material is carried into the Taganrog Bay during the most severe storms. There is no evidence of a similarly large-scale migration of material in the opposite direction. The plumes are separated by narrows adjacent to the straits between the islands.

The width of the shoal zone is 250-500 m (Fig. 8). The greatest variety of landforms and their dynamics are to be found here. Four longitudinal sections can be distinguished according to a number of features (Fig. 8).

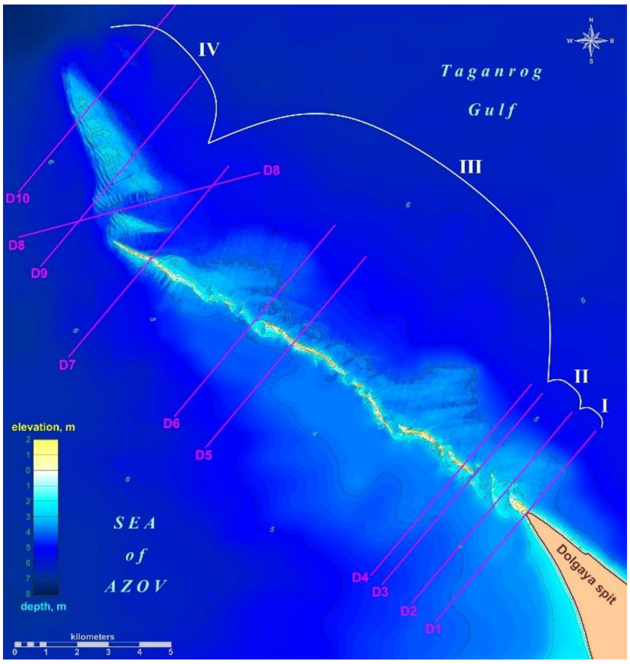


Fig. 8: Digital elevation model of the underwater part of the Dolgaya Spit (based on Sentinel-2 image of 16.10.2019)

The first section (profiles D1-D2) comprises the variable over-water distal of the main part of the Dolgaya Spit and a stable shoal (Fig. 8), which are adjacent to the root part of the Dolgaya Spit. This section is under a constant influence of longshore flow of sediment from the adjacent shore. The direction and extent of the distal part is determined by the volume of sediment discharged along the eroding NE shore and varies with hydrological conditions (Fig. 10). The distal has been eroding in recent decades. At present, the SW side of the distal is reinforced by a drop-fill rock (Fig. 11) and its variability has decreased. At the time of the survey – on 16.10.2019, the length of the distal and adjoining part of the shoal (up to profile D1) was about 650 m. The width of the uppermost part of the shoal was 300-350 m (2 m isobath), and 600 m (3 m isobath). The maximum elevation of the site (including the surface part) above the adjacent seabed was 4 m (Fig. 9).

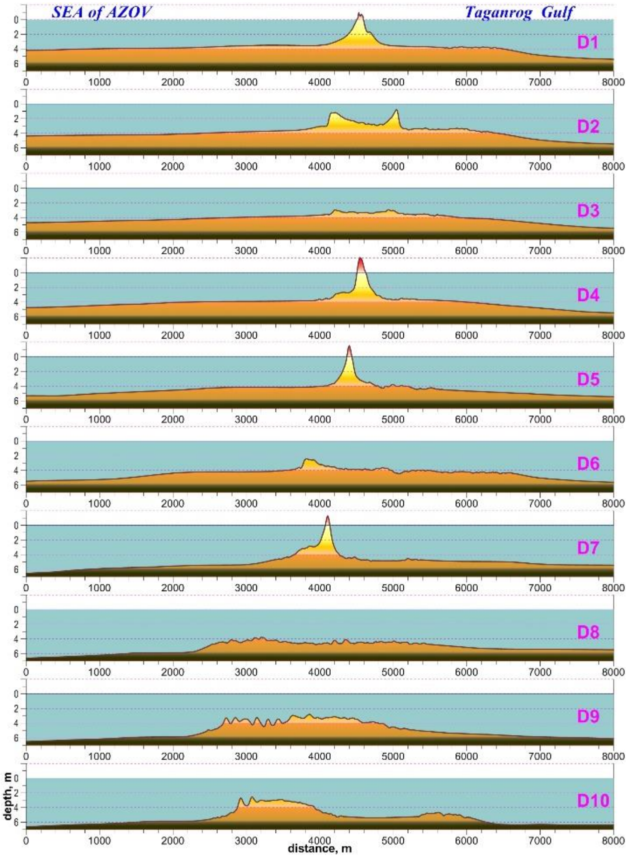


Fig. 9: Examples of transverse profiles of the shallow-island part of the Dolgaya Spit on 16.10.2019 (position of the profiles is shown in Fig. 8)

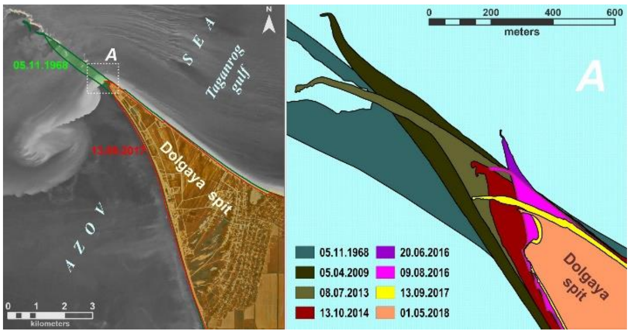


Fig. 10: Transformation of the distal part of the Dolgaya Spit

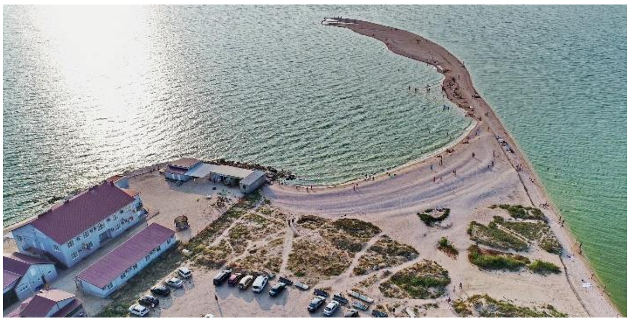


Fig. 11: Tip of the Dolgaya Spit on 22.08.2018

The next section between profiles D2-D3 (Fig. 8) on the accumulative body axis is 1700 m long and it is a zone of active water exchange occurring between the open Sea of Azov and the Taganrog Bay. In this area, the crest of the shallow-island part drops deeper than 3 m and is hardly expressed in the relief (Fig. 9). No islands have been formed here since 2014; in the preceding period, gullies in the accumulative body most often occurred here. The formation of gullies in this part probably prevents the rest of the Dolgaya Spit from destruction. The site formed crescentic positive landforms (Fig. 12) located at a 45° angle to the longitudinal axis of the accumulative body. They have an asymmetric cross-section profile (profile D2) reflecting predominance of sediment movement towards the bay. The elevation of these forms above the surrounding seabed is 2-2.5 m and they are separated by flat sections of the seabed (profile D3). The structure of this seabed relief in this area casts doubt on current existence of longshore flow of sediment from the tip of the main part of the Dolgaya Spit towards the shallow islands. Such flow may form when there is an excess of sediment. At this time there will be direct migration of sediment along the growing distal part of the spit all the way to the tip of the submarine shoal. However, when there is a shortage of sediment (as at present) the longshore inflow of material is insufficient to close gaps (gullies) and the dynamics of the site bottom relief is predominantly determined by lateral movements of the material.

The third (central) section is the longest at 13.75 km (Fig. 8). It is characterised by a chain of islands and well-defined submarine elevations, with periodically formed above-water parts, arranged clearly along the longitudinal axis. The elevation of the islands (including the above-water part) is 4-6 m above the surrounding seabed. The cross profile of the shoals is symmetrical and their width along the 3 m isobath is within 300-400 m (Fig. 9). The shoals are separated by more or less pronounced straits 100 to 500 m wide that cross or angle the axis of the shallow-island part. The bottom relief of most straits reflects the influence of powerful reverse flows of water masses. A narrow can be seen in the central part of the straits. At the exit from the straits, arc-shaped hills that mark areas of unloading of material discharged by the flow from the accumulative body can be clearly seen. These shapes are similar to bars situated near the mouth of a river. Characteristically, these bars are located on opposite sides of the straits, confirming the bimodal nature of the currents in them.

During periods of low hydrodynamic activity, when sediment is consolidated along the axis of the shallow-island area, the length of the island chain can vary from a few hundred metres to 2-3 km. The width of the emerging islands does not exceed 100 m, the height is up to 2 m at sea level. At the tip of the islands small hooks (locally called 'dzendziki') are formed, oriented in the direction of the prevailing current. The islands are the most 'ephemeral' element of the relief of the shallow-island part of the Dolgaya Spit. They can be formed and destroyed during a single storm, their configuration changes as currents change in the straits. Nevertheless, there is no doubt that even after complete destruction and under conditions of deficient longshore flow of sediment, islands re-form within a few years (Fig. 12). It is conceivable that the primary mechanism for consolidation of material within this section of the submarine-island part of the Dolgaya Spit is transverse movement of sediment close to the line separating the Taganrog Bay from the open Sea of Azov. This is indicated by the presence of pronounced straits between the islands at the time of their formation. It is only when sufficiently long islands have formed that local longshore flow of sediment is formed along them, lengthening the islands and gradually closing off parts of the straits. Characteristically, each of the islands lengthens simultaneously in both directions, bridging the straits. This contradicts the existence of a single longitudinal flow from the tip of the Dolgaya Spit to the NW. As the edges of the islands bend in the direction of the prevailing wave or current at a particular period, the junction point of the countercurrent flows is diverted from the axis along which the primary islands originated, and the entire island chain takes on a sinuous appearance (Fig. 12). In some cases, the development of surface accumulative bodies is observed, straightening the previously formed bend. As the islands lengthen, longshore currents intensify and they may also change the configuration of the shoals that serve as the islands` foundation. During storm surges there are breaks in the above-water part of the islands. Reconstruction of the junctions takes place under different hydrological conditions and the attachment of neighbouring islands may take place elsewhere.

To the south of profile D7 there are transversal ledges on both sides of the shoal, 150-200 m apart, with an average elevation of 0.5-1.0 m above the seabed. The ledges were presumably formed by the interaction of transverse (surge and seiche) and longitudinal currents that form along its sides. The presence of similar water motions caused by turbulence as large masses of water pass through can be seen in the structure of turbidity patches on satellite images (Fig. 13).

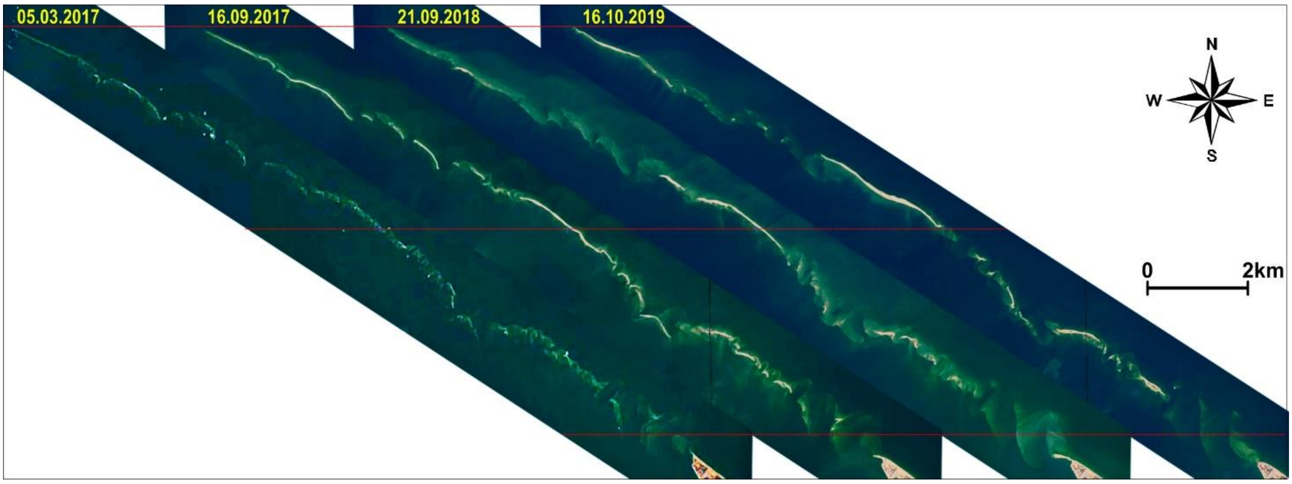


Fig. 12: Transformation of the shallow-island part of the Dolgaya Spit within two years

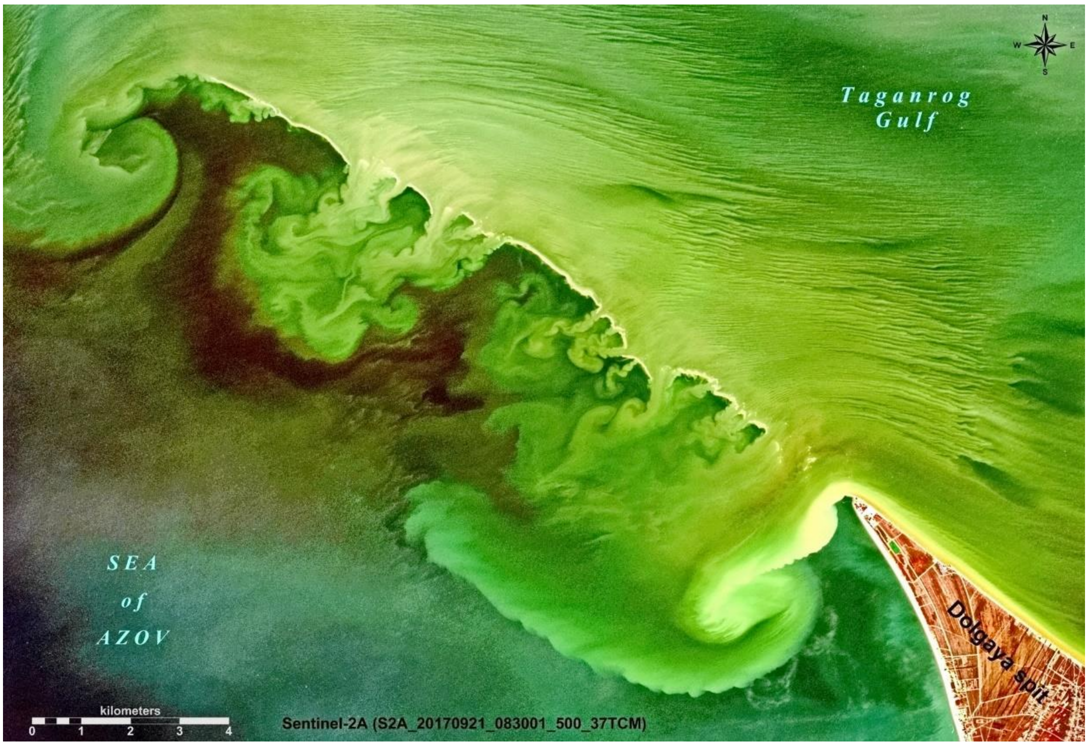


Fig. 13: (Sentinel-2 image fragment, 21.09.2017)

Near the northern tip of the shallow-island part of the Dolgaya Spit (Section 4) (Fig. 8, 14) there are underwater landforms indicating the presence of oscillatory movements of large water masses. These forms have been traced on satellite images since at least 2015. Over 6 km long and up to 3 km wide, there is a system of ridges perpendicular to the currents in the strait. There are up to 10 sub-parallel ridges traced (Fig. 9, 14), with a crest elevation of 1-1.5 m above the narrows separating them, the distance between adjacent ridges is 100-150 m (profiles D9-D10). The transverse profile of the ridges is close to symmetrical. To the east, smaller ridges or plumes are formed on top of these ridges and perpendicular to them. The distance between these ridges is about 50-60 m and the elevation above the bottom is about 0.3 m.

Relief formation mechanisms in the shallow-island part of the Dolgaya Spit

Analysis of the structure of the shallow-island part of the Dolgaya Spit, based on the digital elevation models obtained, revealed a number of characteristic features. Along the axis of the accumulative body there are shoals with a complex configuration and an abundance of drop-shaped or arc-shaped elements. Such hydrogenous bodies are formed by a combination of differently directed sea currents. The presence of depressions crossing or angling the longitudinal axis of the underwater-island part of the Dolgaya Spit indicates a much lesser influence of alongshore sediment transport from the main part, as compared to the transverse one.

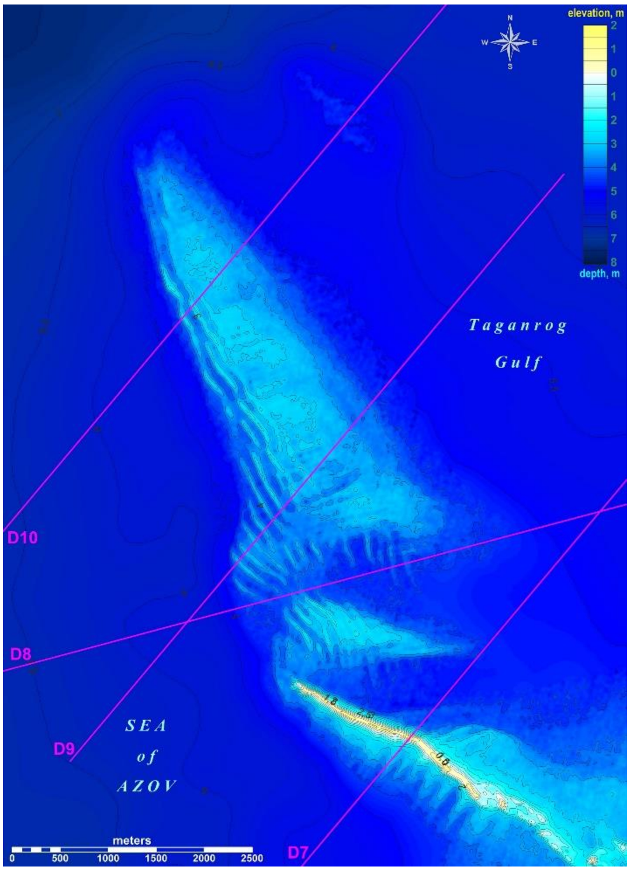


Fig. 14: Hydrogenous underwater landforms at the northern end of the shallow-island area (DEM based on Sentinel-2 image of 16.10.2019)

Along the adjacent shores, the alongshore currents can reach values of 0.4-0.6 m/s with the direction usually towards the tip of the spit. There are no beach-forming fractions in the original rock of adjacent shores (Kosyan, Krylenko, 2019). At the same time, potential capacity of sediment flow is very high. Accordingly, the role of longshore currents along the Dolgaya Spit is limited to the erosion of the root part and transport of sediment to the tip of the distal part of the spit. In addition, these currents, while continuing to move along the shallow islands of the Dolgaya Spit, consolidate the sediment previously carried onto the adjacent underwater slope by cross currents and storms.

The shoals and islands are formed mainly by shells, which has considerably greater mobility than mineral sands. The arrival of shell material from the underwater slope and its consolidation near the axis of the shallow-island part is determined solely by the nature of the waves. In addition, it is the waves that form the islands on the axis of the underwater-island area. Over the area of the Sea of Azov, the NE winds prevail in winter and SW – in summer. The shallow-island part of the Dolgaya Spit is exposed to waves from opposite directions – SW and NE. The strength of SW disturbances exceeds that of the NE swell, but the frequency of the latter, especially in winter, is higher. On the basis of available wave data (Shlyamin, 1977), at the entrance to the Taganrog Bay during the strongest SW storms shells mobilisation may occur from the entire area of the seabed adjacent to the shoal (depth - 6-11 m). On the side of the Taganrog Bay the supply of the shell material from the seabed is weakened: short waves cannot lift the shells from depths of 5-6 m. Thus, wave disturbance contributes to the flow of the shells from the open Sea of Azov to the Dolgaya Spit and its underwater shoal and its consolidation near the axis of the accumulative body.

The complex combination of factors at work determines the particular configuration and transverse structure of the islands that form along the axis of the accumulative body. The surface relief of the islands is represented by a series of shell beach bars extending along both shores (Fig. 15). The size (height and width) of the beach bars corresponds to the intensity of the wave from a given direction. There are often lagoons forming between the beach bars. As a rule, islands are formed independently of the state of the main part of the spit and are connected to it only in the presence of a significant excess of sediment brought in by longshore flow. Restoration of the lithodynamic connection alters somewhat the overall development of the area – the role of the longshore flow increases. At such times, the length of the main (shore-connected) part of the accumulative body increases due to its extension to the NW. Nevertheless, the influence of transverse sediment movement persists and the height and width of the beach bars on either side of the Dolgaya Spit continue to increase. In phases of sediment deficit the accumulative body divides into two almost independent parts once again – the main, predominantly over-water part and the shallow-island part, predominantly underwater. The observed disintegration of the single accumulative body is often perceived as its degradation, but this is only a phase of its development.

As the shallow-island part of the Dolgaya Spit acts as a barrier at the entrance to the Taganrog Bay, high sea level gradients occur over it as a result of up and down surges. Strong W-SW winds in Taganrog Bay produce a surge of up to 2-3 m. In contrast, during sustained NE wind there is a downsurge of up to 1-1.5 m. During the initial and final stages of the up and down surge cycle, currents of up to 1-1.5 m/s form in the straits. As a rule, these currents cover the entire water column, from the surface to the bottom. In general, such transverse water movement contributes to the formation of gullies in the shallow-island area and sediment transport to the adjacent underwater slope (Fig. 16).

Fig. 15: Island relief (photo surf-shelter.ru)

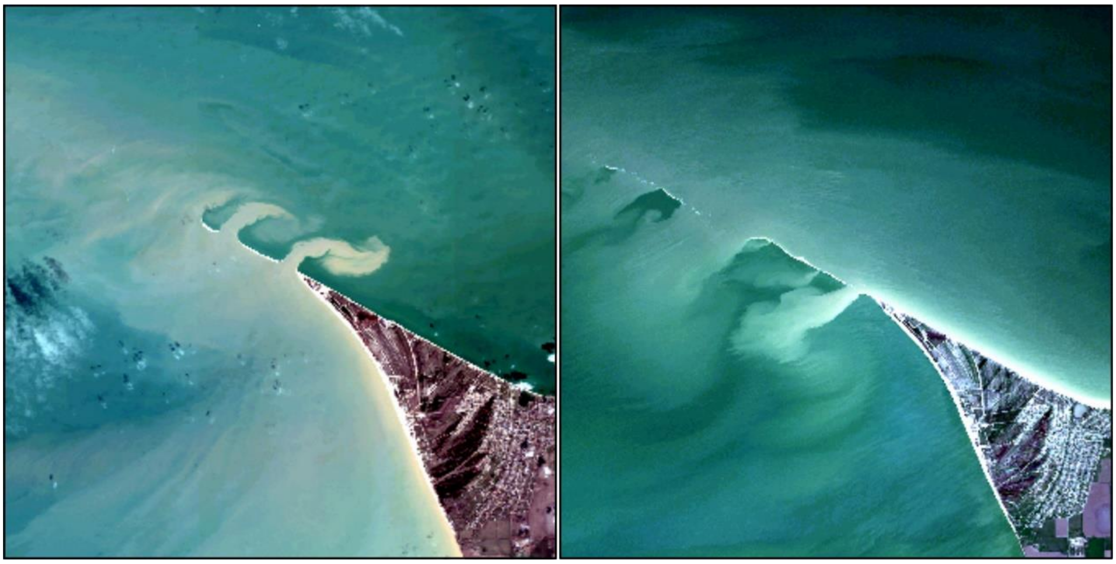


Fig. 16: Movement of water masses at the Dolgaya Spit. On the left – SW storm, eroding the SW coast of the Yeysk Peninsula and carrying sediment from the open Sea of Azov into the Taganrog Bay; on the right – NE storm, eroding the NE coast and carrying sediment into the open Sea of Azov

During the maximum development phase of the surge in the mouth of the Taganrog Bay, there are strong compensatory currents in the near-bottom layer directed from the Taganrog Bay to the open sea. During a field experiment in August 2000 at the exit of the Taganrog Bay at the end of the Dolgaya Spit there were intense near-surface and near-bottom currents with speeds of 60-90 cm/s and 40-60 cm/s respectively, directed in the opposite direction (Luk'yanov et al., 2001, Zakharevich, Sukhinov, 2001). A compensatory current originating in the near-bottom layer and covering a large area of the bottom of the Taganrog Bay contributes to the movement of the shells towards the underwater shoal of the Dolgaya Spit. After passing over the underwater shoal in the open sea, the near-bottom compensatory current quickly fades and sediment accumulates close to the shoal, in the zone of lithodynamic influence of waves of SW direction. Thus, the compensatory current is the driving force behind the process of shell transport from the bottom of the Taganrog Bay into the lithodynamic system of the Dolgaya Spit.

In addition to the processes listed above, the presence of a discharge current from the mouth of the Don towards the open Sea of Azov and alternating currents initiated by seiche should be considered. The process of island reshaping is also influenced by drifting ice.

Thus, the combined effect of wave action contributes to the influx of sediment into the lithodynamic system of the Dolgaya Spit from the open Sea of Azov. In addition, wave action promotes consolidation of sediment along the axis of the shallow-island area and formation of islands. The compensatory current, reinforced by the discharge current, contributes to the influx of sediment from the NE, from the side of the Taganrog Bay. The longshore currents, directed from the adjacent shores of the Yeysk Peninsula to NW, towards the tip of the Dolgaya

Spit and its underwater shoal, contribute to a gradual spread of sediment along the axis of the accumulative body and increase its length. The logical lithodynamic result of the combined action of the above phenomena was the quasi-stationary spatial position of the axis of the shallow-island part of the Dolgaya Spit. At the same time, the variety of acting factors contributes to a high variability and diversity of the hydrogenous forms that form along the axis of the accumulative body.

Sea level, the hydrological and wind-wave regimes and the sediment load are the main factors that determine the dynamic equilibrium of the shallow-island part of the Dolgaya Spit and its relief. The position of the accumulative body at the entrance to the Taganrog Bay is determined by the combined action of waves and currents of different genesis. Accordingly, a short-term change in any of these factors leads to a rapid transformation of the underwater relief. Variable water movements caused by surge and seiche phenomena contribute to the consolidation of sediment near the axis of the accumulative body, but at the same time can cause erosion in some areas. Waves contribute to the formation of islands and initiate longitudinal movement of sediment. If the current wind-wave climate and hydrological structure of the sea are preserved, the position of the underwater-island part will not change.

When sea level is relatively stable (±1 m), the position of the accumulative body also remains unchanged. However, in the case of a short-term strong sea level rise (of more than 2 m, as during the surge in September 2014), the islands are destroyed. It is likely that if sea level rises significantly, possibly as a result of global climate change, the above-water part of the shallow-island part of the Dolgaya Spit will be completely destroyed, although the underwater part will retain its position in space. A drop in sea level can also have a significant effect, but only at values that cause a change in the configuration of the sea and its current regime. In this case, the change will manifest itself in a change in the orientation of the entire accumulative body, including the above-water and underwater parts.

Fluctuations in the total volume of sediment in the lithodynamic system of the Dolgaya Spit can cause changes in its relief. An increase in the amount of sediment will contribute to the growth of the surface parts and increase in the total length of the shallow-island part. Reduction in the amount of sediment will consequently cause the opposite process. At the same time, fluctuations in sediment volume have no effect on the position of the axis of the accumulative body in space.

Conclusion

The research carried out confirmed the assumption that there is a natural mechanism that determines both an extreme dynamism of the relief of the accumulative body in short periods of time and a high stability of the geosystem as a whole. A striking example of an accumulative body that exists due to such a mechanism is the Dolgaya Spit geosystem. On the one hand, it has the distinctive features of a free accumulative body influenced by longshore sediment flow. The configuration of its upper part is characteristic of many cuspate spits formed by two sediment streams converging at an acute angle. On the other hand, the shallow-island part develops under the influence of alternating transverse movements of water masses and waves from opposite sectors of the horizon. This influence favours the formation of a bar-like accumulative body, consisting of shoals and islands, located at the junction of two large water areas. The coexistence of signs of the bar and cuspate spit provides grounds for classifying the Dolgaya Spit not as a cuspate accumulative body (in particular as an Azov-type spit) but as a separate type of major accumulative geosystems, developing under the active joint action of transverse and longshore sediment flows.

In general, several features can be singled out for such accumulative geosystems:

1. They are located at the junction of two large water areas with opposing forces determining direction of sediment movement – waves, currents (drift, tidal, runoff, compensatory ones). The total power of all forces acting from each direction must be equal.
2. The initial (main) accumulation of sediment in the system is due to longshore sediment flow from the land side (sometimes there are two sediment flows).
3. During periods of sediment surplus, a single spit with an extensive above-water part is formed along the axis of the accumulative body. At this juncture the longshore sediment flow dominates along its coasts.
4. During periods of sediment deficit, the accumulative body is divided into a coastal body, with an above-water spit and longshore sediment flow, and a shallow-island body where transverse sediment flow predominates. During such periods, the lithodynamic connection between the above parts may weaken or even cease.
5. Within the shallow-island part in the zone of equilibrium of the forces acting on both sides, islands may form, representing two bars with lagoons enclosed between them.
6. The entire accumulative body system may gradually shift as the overall configuration of the adjacent shore changes or the balance of acting

forces changes, but the overall lithodynamic pattern of geosystem development remains unchanged.

Funding

Research (part of relief analysis) was funded by Russian Science Foundation grant number 20-17-00060. Research on the dynamics of individual coastal sections was funded by State program № FMWE-2021-0013.

Acknowledgements

Information on the dynamics of individual coastal sections was obtained within the framework of the State program № 0128-2021-0013.

Author contribution

Conceptualization, Viacheslav Krylenko and Marina Krylenko; methodology, Viacheslav Krylenko; formal analysis, Viacheslav Krylenko; investigation, Viacheslav Krylenko and Marina Krylenko; writing—original draft preparation, Viacheslav Krylenko and Marina Krylenko; writing—review and editing, Marina Krylenko. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Artyukhin, Yu.V., Artyukhina, O.I., & Rodionova, N.B. (2015). Yeisk coast: history and problems of development, natural foundations of reconstruction. Yeisk, 205 p.

Artyukhin, Yu.V. (1987). Genesis and dynamics of the 'Azov type' spits. *Geomorphology*, 3, 27–30.

Bespalova, L.A. (2007). Ecological diagnostics and assessment of the stability of the landscape structure of the Sea of Azov. Saint Petersburg State University, 32 p.

Budischev, I.M. (1808). Sailing Directions and the sea guide to the Sea of Azov. Saint Petersburg, 79 p. www.bookvoed.ru/files/3515/18/73/47.pdf

Chybicki, J. (2017). Mapping south Baltic near-shore bathymetry using Sentinel-2 observations. *Polish Maritime Research*, 24, 15-25. https://doi.org/10.1515/pomr-2017-0086

Fisher, R.F. (1955). Cuspate spits of St. Lawrence Island, Alaska. *Jour. Gool.*, 63(2), 133-142.

Hedley, J.D., Harborne, A.R., & Mumby, P.J. (2005). Simple and robust removal of sun glint for mapping shallow-water benthos. *Intern. J. Remote Sensing*, 26(10), 2107-2112. https://doi.org/10.1080/01431160500034086

Khrustalev, Yu.P., & Scherbakov, F.A. (1974). Late Quaternary deposits of the Sea of Azov and the conditions of their accumulation. *Rostov-on-Don: Publishing House Rostov University*, 154 p.

Kosyan, R.D., & Krylenko, M.V. (2019). Modern state and dynamics of the Sea of Azov coasts. *Estuarine, Coastal and Shelf Science*, 224, 314-323. https://doi.org/10.1016/j.ecss.2019.05.008

Krylenko, V., Aleinikov, A., Krylenko, M., Beliaeva, N., & Moiseeva, N. (2019). Possibility of the underwater topography studying of large accumulative forms according to Sentinel-2 data. *Proc. of SPIE*, 11174, 111741P. https://doi.org/10.1117/12.2532292

Krylenko, V., & Krylenko, M. (2017). Long-term Dynamics of the Dolgaya Spit Coast. *Proc of the XIII International MEDCOAST Congress on Coastal and Marine Sciences, Engineering, Management and Conservation*. Mugla: MEDCOAST Foundation, 2, 839-848.

Krylenko, V., Krylenko, M., & Aleynikov, A. (2019). Revision of the coastline length of the Azov Sea according to remote sensing data. *Proc. of SPIE*, 11174, 111741B. https://doi.org/10.1117/12.2532690

Krylenko, V., & Krylenko, M. (2018). High-precision relief survey of the Bakal spit. *Environmental safety of the coastal and offshore zones of the sea*, 4, 65-72. https://doi.org/10.22449/2413-5577-2018-4-65-72

Luk'yanov, Yu.S., Tsytsarin, A.G., Sukhinov, A.G. (2001). Investigation of hydrophysical and hydrochemical fields for the purpose of monitoring marine water bodies. *Physical problems of ecology*, 8, 15-22.

Lyzenga, D.R., Malinas, N.P., & Tanis, F.J. (2006). Multispectral bathymetry using a simple physically based algorithm. *IEEE Transactions on Geoscience and Remote Sensing*, 44(8), .2251-2259. https://doi.org/10.1109/TGRS.2006.872909

Mamykina, V.A., & Khrustalev, Yu.P. (1980). The Sea of Azov Coastal zone. *Rostov-on-Don: RSU Publishing House*, 176 p.

Matishov, G., Polshin, V., Kulygin, V., Titov, V., Kovalenko, E., & Sushko, K. (2020). New data on the structure of the Dolgaya spit of the Sea of Azov (drilling, study of outcrops, malacofauna). *Science in the South of Russia*, 16, 3, 26–39. https://doi.org/10.7868/S25000640200304

Matishov, G., & Polshin, V. (2019). New result on the history of the Azov Sea in the Holocene. *Reports of the Academy of Sciences*. 15, 1, 42–53. https://doi.org/10.7868/S25000640190105

Matishov, G.G., Gargopa, Yu.M., Berdnikov, S.V., & Dzhenyuk, S.L. (2006). Patterns of ecosystem processes in the Sea of Azov, M.: *Nauka*, 304 p.

Papacoma http://papacoma.narod.ru/maps-index.htm [Accessed: 15.11.2020]

Price, A.W., & Wilson, B.W. (1956). Cuspate Spits of St. Lawrence Island, Alaska: A Discussion. *The Journal of Geology*, 64, 1, 94-98. https://doi.org/10.1086/626321

Rosen, P.S. (1982). Cuspate spits. In: Beaches and Coastal Geology. *Encyclopedia of Earth Sciences Series*. Springer, New York. https://doi.org/10.1007/0-387-30843-1_143

Rosen, P.S. (1975). Origin and processes of cuspate spit shorelines, in L. E. Cronin, ed., Estuarine Research. *New York: Academic Press*, 2, 77–92. https://doi.org/10.1016/B978-0-12-197502-9.50010-1

Sentinel Online technical website. Available at: https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi/level-1c/product-formatting [Accessed: 10.01.2020]

Shlyamin, B.A. (1977). Waves on the Sea of Azov. *Trudy GOIN*, 16, 45-47

Stumpf, R., Holderied, K., & Sinclair, M. (2003). Determination of water depth with high-resolution satellite imagery over variable bottom types. *Limnol. Oceanogr.*, 48(1), 547-556. https://doi.org/10.4319/lo.2003.48.1_part_2.0547

Sukhomlin, A.M., 1854 (2017). Sailing directions of the Sea of Azov and the Kerch-Yenikalsky Strait. Nikolaev, 4, 96 p.

Traganos, D., Poursanidis, D., Aggarwal, B., Chrysoulakis, N., & Reinartz, P. (2018). Estimating satellite-derived bathymetry (SDB) with the Google Earth Engine and Sentinel-2. *Remote Sens.*, 10(6), 859-877. https://doi.org/10.3390/rs10060859

Zakharevich, V.G., & Sukhinov, A.I. (2001). Mathematical modeling is a universal methodology for analyzing and forecasting the ecosystem of the Sea of Azov. *Proceedings of the Southern Federal University*, 20 (2), 3-13

Zenkovich, V.P. (1967). Processes of Coastal Development. *Oliver and Boyd*, Edinburgh, 738 p.

Zenkovich, V. P. (1959). On the genesis of cuspate spits along lagoon shores. *Jour. Geology* 67, 269–277

Zenkovich, V.P. (1958). Shores of the Black and Azov Seas. *M.: Geografizdat*, 359 p.

Zimin, M., Moiseeva, N., Belyaeva, N., Aleynikov, A., Savostin, A., & Perminova E. (2018). Bathymetric mapping in the coastal zone based on Earth remote sensing materials. *RRW by SCANEX R&D Centre*, 91 p.

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **123**-**132**
http://dx.doi.org/**10.5775/fg.2022.213.d**

Estimating organic carbon in soils modified by technical processes in Kula Municipality (Bulgaria)

Alexander SARAFFOV[1,*], Petko BOZHKOV[1], Borislav GRIGOROV[1]

[1] Faculty of Geology and Geography, Sofia University “St. Kliment Ohridski”, Tsar Osvoboditel Blvd., 15, Sofia 1504, Bulgaria
* *Corresponding author*: saraffov@gea.uni-sofia.bg

Received on 26-04-2022, reviewed on 06-07-2022, accepted on 09-10-2022

Abstract

The current study focuses on the investigation of soil organic carbon in Technosols in Kula Municipality. It has several aims. There is a need of a provision of more data, regarding carbon sequestration rates in topsoils in plains that are formed in subhumid climatic conditions. Another aim is to check the comparability of the in-profile cultural layer with other ones that are built in different climatic conditions. Objects of the research are contemporary since buried soil horizons play a major part on the provision of essential ecosystem services. The characteristics of soil organic matter are determined by a chemical analysis of six soil samples in the laboratories of the Institute of Soil Science, Agrotechnologies and Plant Protection (ISSAPP) “N. Pushkarov”. The total carbon content is determined by the test of Turin and soil color is determined by Munsell Soil Color Charts (1975). Soil organic carbon values in topsoil vary from 670,000 tons/ha to 1,240,000 tons/ha. Organic carbon in the studied sites represents less than 1% of the soil sample. The study may be regarded as the first step in the assessment of Bulgarian Technosols and their role in the global carbon cycle.

Keywords: *technosols, horizons, artifacts, carbon pool, vertisolage process*

Rezumat. Estimarea conținutului de carbon organic din solurile modificate prin procese tehnologice în cadrul municipalității Kula (Bulgaria)

Studiul de față analizează conținutul de carbon organic din cadrul tehnosolurilor din municipalitatea Kula, având mai multe scopuri. Este nevoie de furnizarea mai multor date cu privirea la ratele de izolare a carbonului în straturile superioare de sol din zonele de câmpie care s-au format în condiții climatice subumede. Un alt scop îl reprezintă verificarea comparabilității stratului cultural în profil cu altele care s-au constituit în condiții climatice diferite. Obiectivele lucrării sunt de actualitate întrucât orizonturile îngropate de sol au un rol major pentru asigurarea serviciilor esențiale ecosistemelor. Caracteristicile materiei organice din sol au fost determinate cu ajutorul analizei chimice a șase mostre de sol în laboratoarele Institutului de Științe ale Solului, Agrotehnologii și Protecția Plantelor *N. Pushkarov*. Conținutul total de carbon este determinat cu ajutorul testului Turin, iar culoarea solului cu ajutorul diagramelor Munsell (1975). Valorile pentru conținutul de carbon organic din stratele superioare ale solului variază de la 670 000 t/ha la 1 240 000 t/ha. În cazul siturilor studiate, carbonul organic reprezintă mai puțin de 1% din mostre. Studiul poate fi considerat ca un prim pas în evaluarea tehnosolurilor din Bulgaria și a rolului acestora în ciclul global al carbonului.

Cuvinte-cheie: *tehnosoluri, orizonturi, artifacte, acumulare de carbon, proces de vertisolaj*

Introduction

The International Union for Soil Sciences (IUSS) included a new category in the World Reference Base for Soil Resources (WRB) in 2015, which represents one the most discussed subjects in present day science - soil organic carbon. It was distinguished from anthropogenic organic carbon, which is a product of artifacts, included in the soil profile. Soil organic carbon or humus composition in a soil horizon is among the diagnostic criteria in the World Reference Base for Soil Resources (WRB). It plays a major part in the carbon planetary carbon cycle. As a matter of fact, soils are regarded as the largest reservoir for carbon in the world. Soil organic carbon levels are constantly influenced by a variety of naturally occurring processes. At the same time the anthropogenic pressure also takes its toll and leads to changes that have never been seen before.

Technogenic activities (coming from the Greek word of “technikos”) lead to the creation of art, craftsmanship and artifacts that are characterized by well-preserved or changed chemical and mineralogical properties. According to the International Union for Soil Sciences (IUSS) artifacts are created, modified or extracted by man, but with a preserved substance composition in general from the moment of their making. Archaeological soils contain more than 20% artifacts in their horizons. They belong to the group of the Technosols (TC), along with the second group of Anthrosols (AT) that is actually representing intensively managed soils.

In general, carbon sequestration in soils is occurring with a constant speed. The access of oxygen into soil is facilitated by different agricultural activities. This involves movement into the upper horizons of organic and mineral substances, resulting in oxidation and transfer of carbon dioxide to the atmosphere. At the same time soil organic carbon contents decrease. Sowing leads to a balance of carbon storages. According to the diagnostic instructions of the World Reference Base for Soil Resources (WRB), continuous agricultural activities and the presence of artifacts are diagnostic criteria that are recreating the chronology of human presence in certain territories. The differences in the fractions of soil organic substance are a proof for technogenic transformation of the soil and are an indicator for the presence of ancient and contemporary landscapes and villages in Bulgaria.

The present investigation has several aims. The authors focus on the provision of an insight for carbon sequestration rates in topsoils in plains that are formed in subhumid climatic conditions. Another aim is to check the comparability of the in-profile cultural layer with those that are formed in other climatic conditions. Objects of the study are contemporary and buried soil horizons that are providing a series of ecosystem services. The link between the geographical and the cultural and historical landscapes is essential. This intersection has led to a sedentary lifestyle, ritual activities and extraction of materials. We intend to investigate the function "e", of the Soil Functions of the Bulgarian Soil Legislation (2018), namely the preservation of biodiversity, carbon contents and genealogical and archaeological heritage.

There are several studies that should be focused on when it comes to soil research and the investigations of Ghimire et al. (2009), Perez and Garcia (2017), Tcherkezova et al. (2019) and Antonov et al. (2019) are among them. They may act as stepping stones, serving for further investigation. Tipping et al. (2017) focused their research on how atmospheric nitrogen deposition affects soil carbon. The authors of the investigation provided a series of examinations in specially chosen semi-natural landscapes in Britain, focusing on the study of anthropogenic change. They conducted mathematical calculations for the epoch of the Holocene with a focus on British semi-natural soils. Wu et al. (2018) participated in another interesting soil study. The authors worked on different management strategies on Chinese territory, aiming at the reduction of greenhouse gases in the battle against global warming. Their investigation is based on Anthrosols and they were researched for a prolonged period of time. Regardless of the fact that these soils are a part of paddy fields in Southern China they are providing sufficient data from a similar research, as the current one. Another study, aiming at unveiling anthropogenic use levels is conducted by Bhardwaj et al. (2019). Their investigation focuses on alluvial soils in the soil research institute in Karnal, India (the Indo-Gangetic Plain). Their results point out that human interference changes the carbon pool of the soil.

Material and Methods

The sampled areas in the investigated territory represent two archeological sites with mean coordinates 43°52′15.53″ N, 22°29′43.29″ E and 43°50′45.8″ N, 22°33′49.8″ W respectively (Fig. 1). Both areas are completely within the extent of the West part of the Danubian Plain, distanced from each other at about 6.5 km. The mound necropolis near the municipal center (Kula town) is elevated at 218 m above sea level. It is discovered and studied by the team of assistant professor Tanya Hristova (2020), which dates the artifacts from the end of the Late Bronze Age and the transition to the Early Iron Age. The early medieval settlement from the VII-IX century AD, discovered by the team of assistant professor Galina Grozdanova (2020) is located West - Southwest of the village of Kosta Perchevo at 219 m.

The area of Kula Municipality includes three adjacent river basins, which determine the general configuration of its boundaries. The shape of the municipal area is closer to an ideal geometric figure (a rectangle), tilted to the Northeast towards the Danube river. The highest point within the area of interest, with an elevation of 490 m, is part of Vrashka Chuka Ridge. Two distinctive levels can be defined based on elevation values - lowland or floodplain (with elevation up to 200 m) and hilly areas (with elevation exceeding 200 m). The West part of the study area includes hills and ridges (such as Bachia Ridge) which are peripheral units of Fore-Balkan's vicinity. River terraces and the floodplain cover the majority of the Northeast and central parts of the study area. The drainage network is represented by streams with variable discharge, characterized by low flow in spring and autumn, pluvio-nival and karst regimes. Watersheds between Kosta Perchevo village and the town of Kula are overlaid with Pleistocene aeolian, alluvial and deluvial deposits (loess clays). River incisions reveal outcrops of Neogene sands, sandstones, and detrital limestone of the Dimovo Formation (Filipov et al., 1992).

The high amount of clay fraction and the slickensides (vertisolage process) are typical features of soils, covering the lowlands and floodplains in Kula Municipality. The genesis of clays is a result of contemporary and/or previous hydromorphism/hydromorphic stages. The soils in the area of interest were used for agricultural purposes; hence the carbon balance was disturbed. Soil organic matter was subjected to the oxidation and removal of atmospheric CO_2 by plants. According to Zhiyanski (2014) "carbon sequestration in soils" includes both emissions of carbon into the atmosphere and its storage in the form of soil organic matter. Therefore, the presented study is inspired by the finding of Zomer et al. (2017 a, b). Their research was focused on the potential of agricultural territories on global scale to sequestrate carbon. The authors aimed at the topsoil layer from 0 cm to 30 cm and provided a map of 250 m resolution. Soil organic carbon storages in tons per hectare are provided per pixel value. In order to receive correct data each value should be multiplied by 100. The research team created another map with data about the future carbon sequestration for the next 20 years.

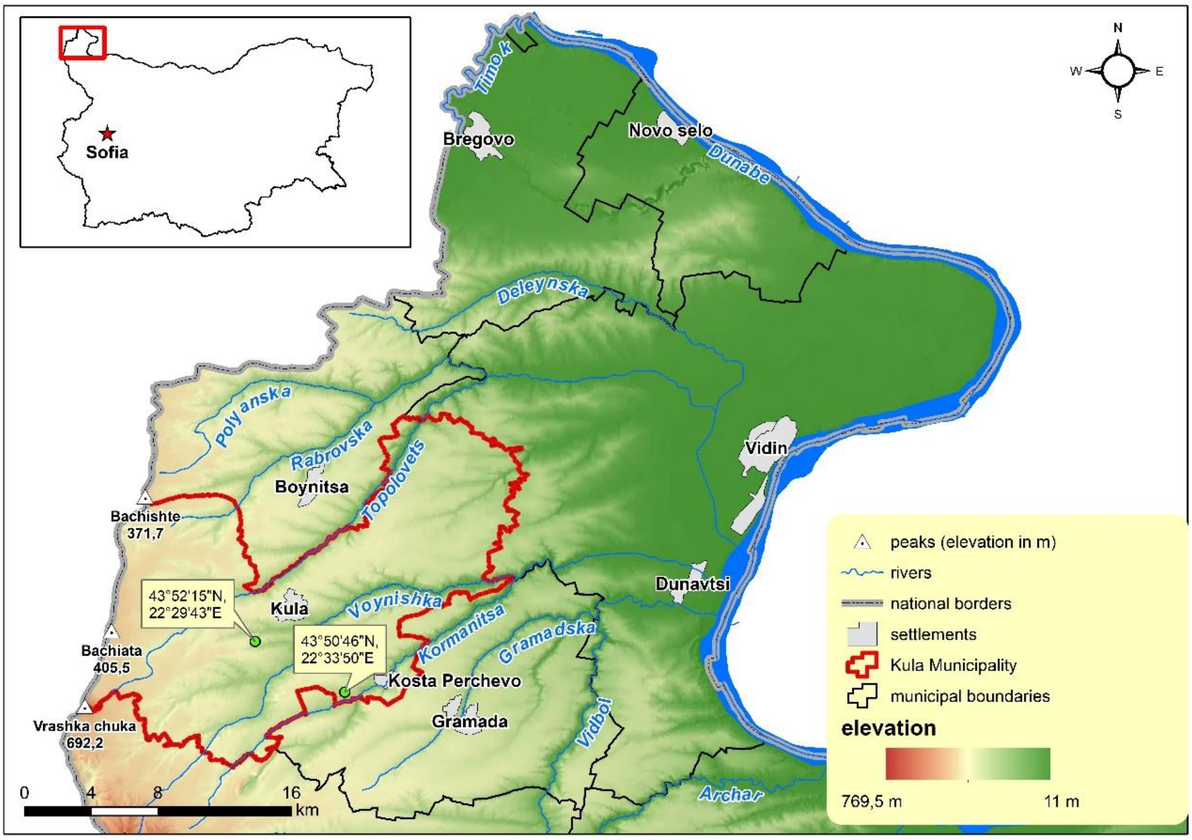


Fig. 1: Study area and sampled soil profiles

The amount and composition of soil organic matter is determined by a chemical analysis of six soil samples. All samples are tested in the laboratories of the Institute of Soil Science, Agrotechnologies and Plant Protection (ISSAPP) "N. Pushkarov", Sofia. The total carbon content is determined by the test of Turin after Kononova (1963) according to the current standards in the country. Thus the humus content is calculated by multiplying the percentage of total carbon by 1.724. Soil profiles in each archeological site are presented by a morphological description and are characterized by grain size analysis. Soil color is determined by Munsell Soil Color Charts (1975).

Results and discussion

Morphological observations

The grain size analyses (Fig. 3) of the morphologically defined three horizons (Fig. 2) shows a similarity between the upper two horizons. The differences are in the large fractions (pebble and sand) that are prevailing in the middle and the lower horizons and another difference is in the amount of silt. The large fractions are most commonly met in the middle horizon (40-80 cm). The presence of clay sized particles in the three horizons is a proof for similar genesis. Thus, the deposits are of an eolic origin, probably mixed with their slow movement down the river, following a creep process.

Gentle slopes and low altitude, the close proximity to a spring that is creating an embrional erosional form and the closeness to constant water flow are among the main reasons for the presence of sedentary lifestyle. The second horizon (Fig. 2) showed a presence of pottery and a furnace that were significantly destroyed. The leading researchers of the excavations (Grozdanova & Koleva, 2020) declared that there is a lack of a typical cultural layer, despite the presence of the ceramics of 4 pots. However, the presence of fragments of iron slag and a tube for oxygen regulation that are moved in zones with anomalies (in the third horizon), as well as the bottoms of the pots that have changed because of the high temperature, are a proves for anthropogenic activities.

Fig. 2: Morphological description of the soil-architectural profile/drilling in Object 5/1004 near Kosta Perchevo Village

- 0-40 (60) cm; black clayey, less gravels; 10YR 3/1 very dark gray; weak reaction with HCl;
- 40 (60) – 80 cm; clayey; lighter in color than the upper layer, less sand and gravel; 10YR 4/3 brown; weak reaction with HCl;
- 80-100 cm; whitish to orange with inclusions and smooth gravels; 10YR 6/6 brownish yellow; reacts with HCl.

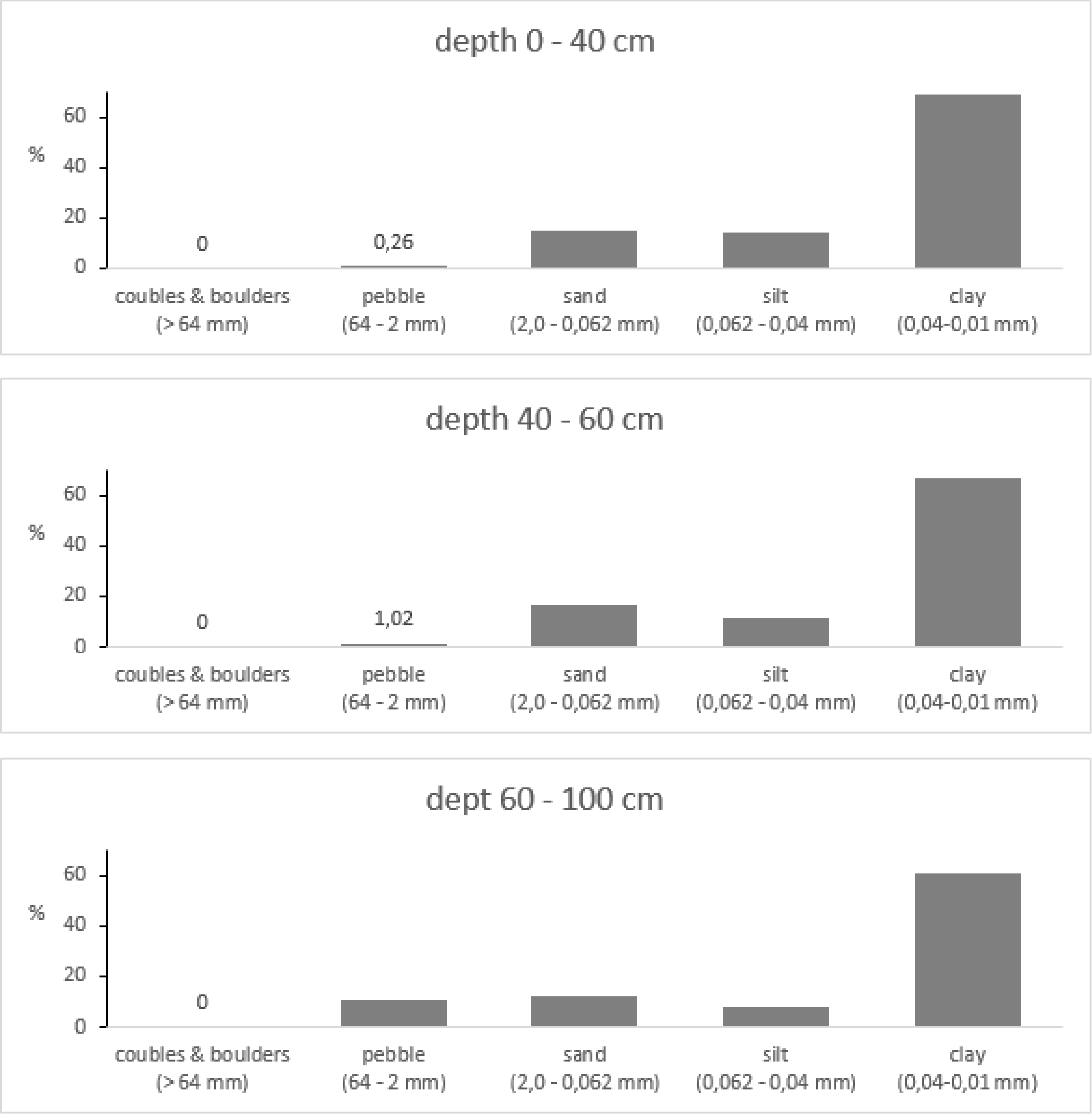


Fig. 3: Results of the grain size analysis

Artifacts also document that the upper horizon of 0-40 cm has developed over the last 10 000 years after the last glacial period. Archaeological structures and the places where urns from the Late Bronze Age necropolis were stored may be associated with the morphological analysis of the third layer (AIII) in Drilling 53 of the object, located near the town of Kula (Fig . 4). It is clear that they were laid in grave pits, leading to a destruction of the AII layer, meaning that it has already been formed in the end of 2nd

millennium BC (Hristova & Hristov, 2020). This is a period of the Early Bronze Age cryophase. The average values of the climatic elements are as low as 2°C, compared to nowadays - a reason for migration from Northern Europe to the territory of Bulgaria (Baltakov & Kenderova, 2003). Ecological conditions were characterized by lush vegetation and more precipitation. If we take the time span and the cultural layer's depth into account, we may assume that soil accumulation during the Subatlantic period in Choika Area, Kula Municipality is with a low speed 0.0067 cm/year.

Fig. 4: Morphological description of the soil-architectural profile/drilling in Object 4/1003 near the town of Kula

- AI 0–10 cm; very dark gray (10YR 3/1), turfy; heavy sand-clayey, compacted, with trochoid-granular structure, vertical cracks, 5 cm wide; it does not react with HCl; well differentiated boundary with the lower horizon
- AII 11-25 cm; dark grey (10YR 4/1); heavy sand-clayey, heavy compacted; structure with small lumps, vertical cracks, reacts with HCl; gradual transition
- AIII 26-50 cm; very dark gray (10YR 3/1); average sand-clayey; compacted, lump-prismatic structure, reacts with HCl.

Heavy clayeness is typical for the mechanical composition of the soil along with colloid consistency. The vertisolage process is the result of successive shrinkage and expansion of the volume due to over humidity and drying. The glance appearance of prismatic aggregates that are diagnostic classification feature adds weight to this assumption.

FAO defines Vertisols as having weak differentiation of the profile if we look at the mechanical composition. Therefore, the composition is similar in the whole soil profile. Subsurface vertic (vr) horizon, starting from a depth ≤ 100 cm of the soil surface, is typical for zonal soils of the reference group that are characterized by a difficult development of the root systems due to the rotation of humid and dry seasons. Swelling clays are a typical feature of the mineral horizon. According to the diagnostic criteria of the working group of IUSS WRB 2015, the il composition has to be ≥ 30% in an area ≥ 25 cm.

The content of organic carbon (Corg.) in the surface very dark gray (10YR 3/1) AI turf layer, with a depth of 0–10 cm (sample 10 - Table 1) of Vertic Chernozems (FAO, 2014) is relatively less than the Corg. in the carbonate type of chernozems. Carbon content decreases in depth reaching 0.38% in horizon AIII (10YR 3/1 very dark gray). Both topsoil and subsurface layers are shallow and although the surface is covered with tufts of grass, the organic content is low. The number of humic acids (3.82%) in the topsoil exceeds fulvic acids due to the uniformity of the grass vegetation in the sampled site, therefore humate type of humus is formed/observed. Fulvic acids in sample 11 (Table 1) were not found while in both surface and subsurface horizons, 0-10 cm and 11-25 cm respectively, free humic acids and those bound with mobile sesquioxides (R2O3) are missing. Results show absence of leaching of humic substances along the depth of the profile.

Carbon content is shown in Table 1 where underlined value indicates the percentage of organic carbon in the soil sample and the other value represents the proportion of total carbon. The type of humus is defined by the ratio between carbons of humic acids to carbon of fulvic acids – Ch/Cf. This ratio is an indication of climate conditions during the soil formation. The higher amount of Cf indicates a weak process of humification, determined by cold and humid climate and presence of forest vegetation, whereas humic acids predominate under grassy vegetation. Total content of humic and fulvic acids (Cextr) is determined after extraction with a mixed solution of 0.1 M (molar) Na4P2O7 and 0.1 M (molar) NaOH (Table 1).

The humic acid fractional composition includes a first fraction of completely free acids and those bound to R2O3, and a second fraction of humic acids bound to calcium extracted with 0.1 M NaOH. The third extracted fraction is of the most mobile, aggressive fulvic acids. The humic and fulvic acids in both extracts Cextr and C extracted with NaOH were separated by acidifying the solution with 0.5 M H2SO4.

The established quantitative share of humic acids in percentage 0.42% relative to the weight of dry soil as a percentage of the total content of organic carbon - 33.07% in the initial sample (sample 10, Table 1) shows a predominance of fulvic acids due to the abundance of wealth grasses with a dense root system.

Topsoil horizon of Vertic Chernozems near Kosta Perchevo Village is also associated with high humus content, hence high amount of organic carbon ($C_{org.}$). The highest carbon content - 1.47% of all compared samples characterizes the most advanced humification process (sample 26, Table 1). Lower C_h/C_f ratio (2.00) is an indication of fulvate-humate type of humus, whereas the type of humus in sample 10 is considered to be humate type. The portion of aggressive fulvic acids extracted with 0.1 M H_2SO_4 is between 3 and 9% of the total carbon, therefore it is relatively low in both soil profiles. Humic acids in both sampled sites are bounded with calcium.

Pottery was found in the second horizon at a depth between 40 (60) and 80 cm (sample 27, Fig. 2). Fulvic acids are also present in this layer while in the lower layer (80 - 100 cm) archeologists found lots of slag, which is the main reason to classify soil sample 15 as a Technosols. Presence of swamp ore (hydrated iron oxide mixed with vegetation matter) could be explained by a low oxygen environment, such as marshes and peat bog formation. Two marshes near the sampled site represent those conditions that led to deposit of hydrated iron oxides and soil hydromorphism. Results from the analyses of sample 28 (Table 1) from seasonally overmoistured state, are similar.

Table 1: Indicators for content and composition of soil organic matter

Sample	Total carbon(%) / humus (%)	Organic carbon (%) extracted with 0.1 M $Na_2P_2O_7$ + 0.1 M NaOH			C_h/C_f	Organic carbon (%) Fraction of humic acids		Unextracted organic carbon (%) ($C_{remaining}$)	Extracted carbon with 0.1 M H_2SO_4 (%)	$\frac{C_h+C_f}{C_{remaining}}$	Extracted C with 0,1 M NaOH (%)
		Total	Humic acids	Fulvic acids		Free and bound with R_2O_3	Bound with Ca^{2+}				
10	1.27 / 2.18	0.53 41.73	0.42 33.07	0.11 8.66	3.82	0.00	100.00	0.74 58.27	0.05 4.94	0.71	0.08 6.30
11	0.38 / 0.65	0.12 31.58	0.12 31.58	0.00	-	0.00	100.00	0.26 68.42	0.02 5.26	0.46	0.04 10.53
26	1.47/ 2.53	0.60 40.82	0.40 27.21	0.20 13.61	2.00	0.00	100.00	0.87 69.18	0.05 3.40	0.68	0.14 9.52
27	0.55/ 0.94	0.19 34.54	0.12 21.82	0.07 12.72	1.71	0.00	100.00	0.36 65.45	0.05 9.09	0.52	0.11 20.00
15	0.38/ 0.65	0.15 39.47	0.15 39.47	0.00	-	0.00	100.00	0.23 60.53	0.02 5.26	0.65	0.06 15.79
28	0.45/ 0.77	0.21 46.67	0.14 31.11	0.07 15.16	2.00	0.00	100.00	0.24 53.33	0.02 4.44	0.87	0.08 17.78

Soil organic content

The following lines are focused on soil organic carbon content, following Zomer et al. (2017 a, b). The information in the text will be supported by the visual representation of the obtained results, presented by two maps (Fig . 5 and Fig. 6). These maps include several main villages, namely from west to east: Golemanovo, Izvor mahala, Kula, Poletkovtsi, Kosta Perchevo, Chichil, Topolovets and Tsar Petkovo. Their specific geographic location will be used as a marker in the analysis of the allocation of soil organic carbon.

Generally speaking, the lowest values of soil organic carbon in the topsoil are presented with the darker shades (brownish) on the first of the two maps (Fig. 5). They are prevailing within the borders of Kula Municipality, covering the largest territories. Carbon stocks are located mainly near the villages of Topolovets, Kula, Golemanovo and Staropatitsa. The values there are in the range of 700,000-750,000 tons/ha with the lowest values to the west of Topolovets – 670,000 tons/ha.

The largest carbon pool with highest values can be discovered in the areas with the lighter colours (yellowish). Carbon contents are ranging from 1,000,000 – 1,110,000 tons/ha near the villages of Golemanovo and Izvor mahala, reaching 1,150,000 - 1,160,000 tons/ha to the north of Kula. The richest carbon pool is located between the villages of Staropatitsa and Poletkovtsi where soil organic carbon stocks in the upper 30 cm are 1,240,000 tons/ha.

There are several blank spots within the map that carry no information, despite that fact they are still an integral part of the cartographic material, providing a specific bunch of data.

Figure 6 presents the expected soil organic carbon contents in the topsoil between 0 cm and 30 cm according to the medium scenario. Zomer et al. (2017 a, b) also provide a high scenario of the carbon pool, but the authors of the current study regard it as a too positive one and decided to omit it from the discussed information. Nevertheless, it should be applied in similar investigations if scientists wish to receive a broader picture of the present day problem with soil organic carbon contents.

Once again areas with lower carbon stocks expectancy are the predominant ones and they are displayed with the darker colors. Carbon contents are reaching 780 000 - 860 000 tons/ha between the villages of Topolovets and Tsar Petrovo to the northeast. At the same time carbon stocks near the villages of Golemanovo, Kula, Poletkovtsi and Izvor mahala to the west are around 880 000 - 920 000 tons/ha. If we focus on the difference between the current situation and the expected within the period of 20 years, it becomes obvious that it is possible to expand the carbon pool with an average of 1 000 000 tons/ha. This would be possible if proper land management techniques are adopted.

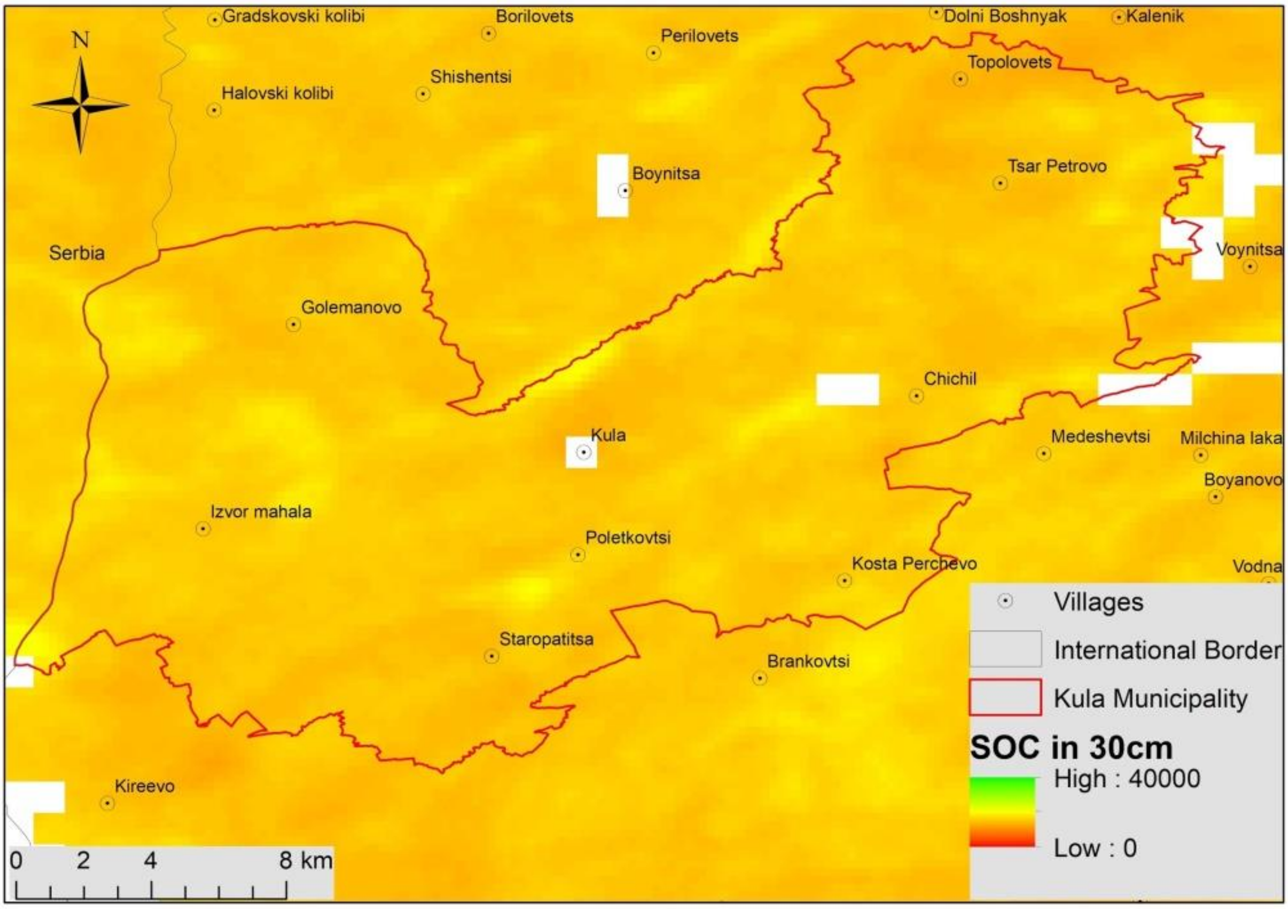


Fig. 5: Soil organic carbon contents in the top 30 cm of the soil in Kula Municipality (according to Zomer et al., 2017 a, b)

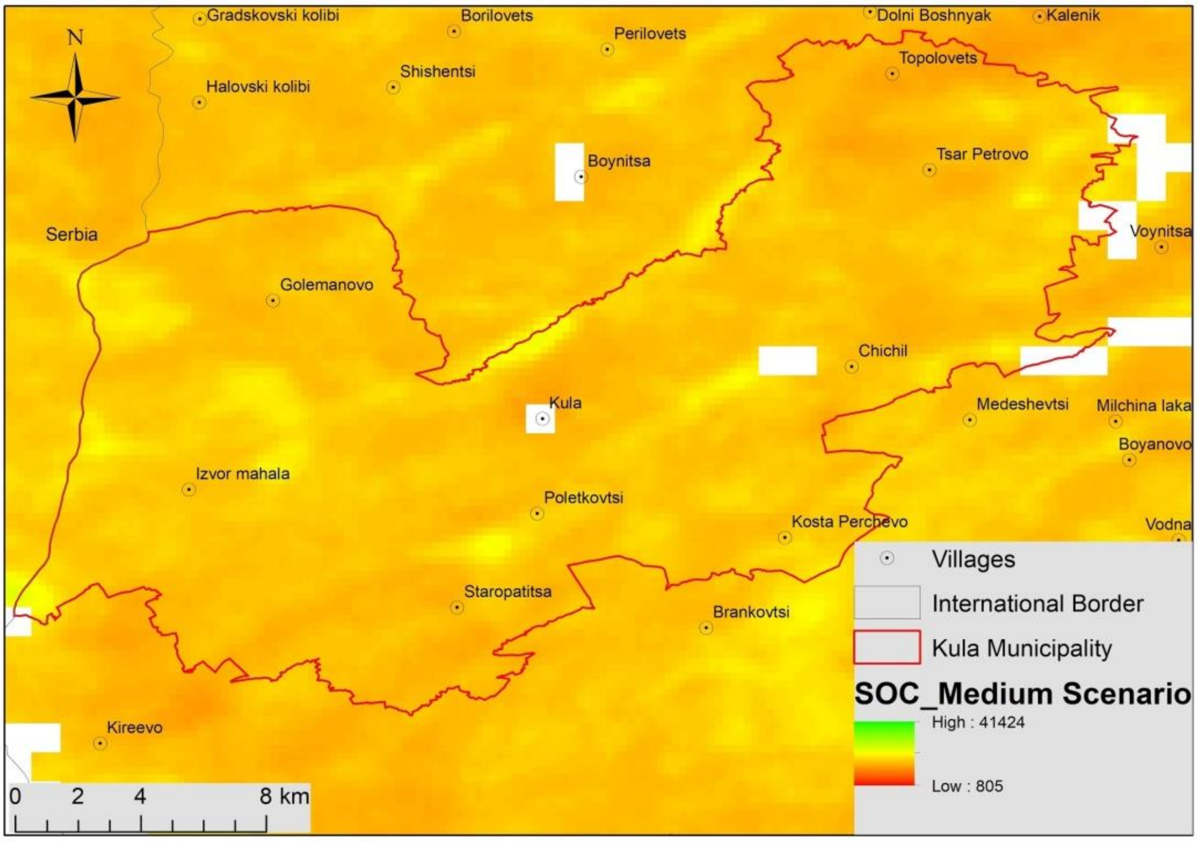


Fig. 6: Soil organic carbon contents in Kula Municipality, as shown in the Medium Scenario. (Following Zomer et al., 2017 a, b)

The medium scenario shows another bunch of data that can be analyzed if we follow the lighter colours on the map. Larger carbon stocks are ranging between 1 100 000 tons/ha and 1 200 000 tons/ha around the villages of Golemanovo and Izvor mahala and over 1 260 000 tons/ha to the west of the settlement of Chichil. The highest values are over 1 350 000 tons/ha to the north of Kula and between the villages of Poletkovtsi and Staropatitsa. Once again an average increase of around 1 000 000 tons/ha may be accomplished if agricultural practices that promote carbon storage are introduced. These results show a typical concordance with some already established rules and they should be referred to by policy makers.

Frank et al. (2018) conducted an investigation that was also aimed at agricultural territories. They calculated that mitigation potentials up to 2050 may be ranging from 10 to 150 $/tCO2eq, which if it multiplied by the expected potential carbon sequestration in the medium scenario, shows a significant amount of money that may be achieved. Another study that is based on cropland areas is the one of Iizumi & Wagai (2019). They are focusing on drought endurance of lands, promoted by the presence of soil organic carbon. Despite Kula Municipality does not fall within the territories that are most susceptible to droughts, like areas in Australia, for example, the expected enhancement of the carbon pool in the medium scenario may play an important part in this matter, as well. Alcántara et al. (2017) investigated a number of sampling territories, including agricultural land in Northern Europe. Their main motivation comes from the expected important role that soil organic carbon sequestration will play in climate change mitigation. They focus mainly on subsoil, unlike our study, in which topsoil is the major player. Fortunately, this does not modify the significance of the soil organic carbon in the first 30 cm of the soil, quite the opposite. Carbon storages in topsoil are as equally important in climate change mitigation and with the expected enlargement of the carbon pool in Kula Municipality; it is going to play an essential role in this process in Northwestern Bulgaria.

A certain measure that may be taken for the improvement of the results of the current research can be the collection of more samples during the terrain observations. The authors agree that the acquisition of data would be a good starting point for even more in-depth analysis. Another road for the perfection of the study is the application of more morphological observations that may add even more value of the successful results.

Conclusion

The current investigation's main focus was on the study of anthropogenic soils in Kula Municipality, Northwestern Bulgaria. As a result of our comparative study on soils modified by technical processes in NW Bulgaria, it was shown that soil horizons and layers had a certain amount of organic carbon in the form of both humic and fulvic acids. Organic carbon in the studied sites represents less than 1% of the soil sample, although it is about 30 to 45% of the total carbon. According to a global model carbon stocks in the study area exceed 1 000 000 tons/ha. The mapped and sampled cultural layer near Kosta Perchevo Village with residues of iron smelting allows us to estimate the organic carbon affected by man-made activity. Therefore, soil is classified as Spolic Tehnosols (form latin spoliare - exploitation) with profile ≥ 20 cm, containing ≥ 20% (by volume) artifacts, of which ≥ 35% are residues from mining, mine dumps sediments after excavation, slag and ash. Cultural layer with artifacts contains indications for soil formation, modified by human technogenic activity. Other two cultural layers are used to date the deposition of artifacts and nowadays represents Urbic Technosols (form latin urbs - city, town) with profile depth ≥ 20 cm, containing ≥ 20% (by volume) artifacts, of which ≥ 35% are building materials and remnants of settlements or sanctuaries in archaeological sites.

The present study, where values of humus, total carbon and soil organic carbon were obtained for spolic (SP) and urbic (UR) horizons, can be considered as the first step in the assessment of Bulgarian Technosols and role in the global carbon cycle. It has displayed some positive outcomes that may be applied in similar studies in the neighboring municipalities and also in other parts of the country.

Funding

The study is supported by the project "Ecosystem/landscape services provided by Technosol in Bulgaria" (contract 80-10-103/16.04.2020), financed by the budget of Sofia University "St. Kliment Ohridski" for scientific research in the year of 2020.

Author contribution

Conceptualization and original draft preparation, A.S., P.B. and B.G.; methodology, A.S.; formal analysis, P.B. and B.G.; investigation, A.S.; writing—review and editing, P.B. and B.G. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest:

The authors declare no conflict of interest.

References

Alcántara, V., Don, A., Vesterdal, L., Well, R., & Nieder, R. (2017). Stability of buried carbon in deep-ploughed forest and cropland soils - implications for carbon stocks. *Sci Rep* 7, 5511 https://doi:10.1038/s41598-017-05501-y

Antonov, D., Kotsev, T., Benderev, A., van Meir, N., Gerginov, P., Stoyanova, V., & Tcherkezova, E. (2019). Estimating the moisture regime in variably saturated arsenic contaminated alluvial sediments by using hydrus-1d with daily meteorological data. *European Journal of Geography*. 10 (2) 42–55. http://www.eurogeographyjournal.eu/articles/3_Antonov_etal_EJG_final_07_08_2019.pdf (Accessed 2020-8-8)

Baltakov, G. & Kenderova, R. (2003). Quaternary paleogeography. Varna, Maleo-63. (In Bulgarian).

Bhardwaj, A., Rajwar, D., Mandal, U., Ahamad, S., Kaphaliya, B., Minhas, P., Prabhakar, M., Banyal, R., Singh, R., Chaudhari, S., & Sharma, P. (2019). Impact of carbon inputs on soil carbon fractionation, sequestration and biological responses under major nutrient management practices for rice-wheat cropping systems. *Sci Rep* 9, 9114 https://doi:10.1038/s41598-019-45534-z

Filipov, L., Decheva, A., Koyumdzhieva, E., Popov, N., & Tsankov, T. (1992). Geological Map of Bulgaria on scale 1:50000, Map sheet Vidin. Sofia, Committee of Geology and Mineral Resources (in Bulgarian).

Frank, S., Beach, R., Havlík, P., Valin, H., Herrero, M., Monsier, A., Hasegawa, T., Creason, J., Ragnauth, S., & Obersteiner, M. (2018). Structural change as a key component for agricultural non-CO2 mitigation efforts. *Nat Commun* 9, 1060. https://doi:10.1038/s41467-018-03489-1

Ghimire, R., Basnet, R., Bista, P., & Ranabhat, B. (2009). Soil Quality Cards for Participatory Soil Quality Assessment in Organic and Smallholder Agriculture. *Forum geografic*, VIII (8), 72-76.

Grozdanova, G., & Koleva, R. (2020). Initial archaeological excavations of Object 5/1004 in Kosta Perchevo Village, Kula Municipality. *Archaeological discoveries and excavations 2019. Book II*, NAIM-BAS, 1271-1274 (in Bulgarian).

Gyurov, G., & Artinova, N. (2015). Soil studies. *Intelekspert*, Plovdiv., 259 p.

Hristova, T., & Hristov, M. (2020). Archaeological research of a necropolis of the final phase of the Late Bronze Age in Choika Area, Kula Municipality. *Archaeological discoveries and excavations 2019. Book II*, NAIM-BAS, 399-402 (in Bulgarian).

Iizumi, T., & Wagai, R. (2019). Leveraging drought risk reduction for sustainable food, soil and climate via soil organic carbon sequestration. *Sci Rep* 9, 19744. https://doi.org/10.1038/s41598-019-55835-y

Kononova, M. (1963). Soil Organic Substance. Its Nature, Properties and Research Methods. ASSU, Moscow, p. 314. (in Russian)

Munsell Soil Color Charts. (1975).

Perez, E., & Garcia, P. (2017). Monitoring soil erosion by raster images, from aerial photographs to drone taken pictures. *European Journal of Geography*. 8 (1) 116-128. http://www.eurogeographyjournal.eu/articles/7.Monitoring%20soil%20erosion%20by%20raster%20images,%20from%20aerial%20photographs%20to%20drone%20taken%20pictures.pdf (Accessed 2021-1-1)

Bulgarian Soil Legislation. (2018). (Updated in the State's Newspaper, vol. 89 as of the 6th of November 2007, with amendments in vol. 80 as of the 9th of October 2009, with amendments in vol. 98 as of the 14th of December 2010, with amendments in vol. 92 as of the 22nd of November 2011, with amendments in vol. 66 as of the 26th of July 2013, with amendments in vol. 98 as of the 28th of November 2014, with amendments in vol. 62 as of the 14th of August 2015, with amendments in vol. 58 as of the 18th of July 2017, with amendments in vol. 98 as of the 27th of November 2018).

Tcherkezova, E., Stoyanova, V., & Kotsev, T. (2019). A concept of an integrated geodatabase for surface water, soil and groundwater pollution with arsenic in the upper part of Ogosta Valley, Northwestern Bulgaria. *European Journal of Geography*. 10 (3) 6–23. http://www.eurogeographyjournal.eu/articles/1_Tcherkezova_et_al.pdf (Accessed 2020-4-4)

Tipping, E., Davies, J., Henrys, P., Kirk, G., Lilly, A., Dragosits, U., Carnell, E., Dore, A., Sutton, M., & Tomlinson, S. (2017). Long-term increases in soil carbon due to ecosystem fertilization by atmospheric nitrogen deposition demonstrated by regional-scale modelling and observations. *Sci Rep* 7, 1890 oi:10.1038/s41598-017-02002-w

Wu, X., Wang, W., Xie, X., Yin, C., Hou, H., Yan, W., & Wang, G. (2018). Net global warming potential and greenhouse gas intensity as affected by different water management strategies in Chinese double rice-cropping systems. *Sci Rep* 8, 779 https://doi:10.1038/s41598-017-19110-2

Zhiyanski, M. (2014). Description of general soil organic carbon pools in forest ecosystems, *Forest Science*, No 1/2, 121-138 (in Bulgarian). https://naukazagorata.files.wordpress.com/2015/07/ng_1-2_2014_13.pdf

Zomer, R., Bossio, D., Sommer, R. et al. (2017a). Global Sequestration Potential of Increased Organic Carbon in Cropland Soils. *Sci Rep* 7, 15554 https://doi:10.1038/s41598-017-15794-8

https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/HYFICT

Zomer, R., Bossio, D., Sommer, R., & Verchot, L. (2017b). Replication Data for: Global Sequestration Potential of Increased Organic Carbon in Cropland Soils, https://doi.org/10.7910/DVN/HYFICT, Harvard Dataverse, V1

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December 2022**), pp. **133-145**
http://dx.doi.org/**10.5775/fg.2022.105.d**

Morphometry and Topographic Wetness Index Analysis for flood inundation mapping in Mata Allo watershed (South Sulawesi, Indonesia)

UCA[1], Mustari LAMADA[2], Sukri NYOMPA[1], Nurul Afdal HARIS[3,*]

[1]State University of Makassar, Faculty of Mathematics and Natural Science, Geography Department, Makassar, South Sulawesi, Indonesia
[2]State University of Makassar, Faculty of Technic, Department of Informatics and Computer Engineering, Makassar, South Sulawesi, Indonesia
[3]Gadjah Mada University, Faculty of Geography, Department of Geographic Information Science, Master Program in Remote Sensing, Bulaksumur,Yogyakarta, Indonesia
* *Corresponding author*: nurul.afdal.haris@mail.ugm.ac.id

Received on 14-06-2022, reviewed on 30-08-2022, accepted on 03-11-2022

Abstract

Lorem Along with climate change, natural disasters will occur more frequently such as floods. Floods that occur in watersheds which include various human activities, such as Mata Allo (Indonesia) will especially cause a large enough impact. The elongated shape of the watershed has a slow response to peak discharge and time lag. The Mata Allo watershed is dominated by slopes above 25%→45% (65%) and agricultural land use which accounts for 53% of the area, which has an obvious impact on the amount of runoff and erosion that occurs. The eroded soil will be carried away by surface runoff and deposited in the plains between mountains and river floodplains. Based on the results of the study, the Topographic Wetness Index (TWI) map indicates that the part between the mountains and the floodplain around the Mata Allo river had a high TWI value. A high TWI value indicates a high vulnerability to anticipate flooding in the event of overflowing from the Mata Allo River. River morphometry, land use, and hydrological behavior in a watershed are closely related to the TWI value in the Mata Allo watershed.

Keywords: *modelling, hydrodynamics, mitigation, flood, watershed, morphometry*

Rezumat. Analiza morfometriei și a indicelui topografic de umiditate pentru cartarea inundațiilor în bazinul Mata Allo (sudul insulei Sulawesi, Indonesia)

Datorită schimbărilor climatice, dezastrele naturale, precum inundațiile, se vor produce cu o frecvență mai mare. Inundațiile din cadrul bazinelor hidrografice unde se desfășoară diverse activități antropice, cum este cazul bazinului Mata Allo, vor avea în mod particular un impact considerabil. Ca urmare a formei alungite a bazinului, propagarea debitului maxim se face lent ceea ce duce la un decalaj și a timpul de producere. În cadrul bazinul Mata Allo predomină pantele cu o înclinare de 25-45% (65%) și terenurile agricole care reprezintă 53% din suprafața totală, ceea ce are un impact evident asupra cantității de apă scursă pe versant și eroziunii. Solul erodat este transportat o dată cu scurgerea de suprafață și apoi depus în zonele mai plane dintre munți și luncile râurilor. Pe baza rezultatelor acestui studiu, harta indicelui topografic de umiditate (ITU) indică faptul că zona situată între munți și luncile râurilor din Mata Allo prezintă o valoare ridicată a acestui indice, ceea ce indică o vulnerabilitate ridicată pentru anticiparea inundațiilor în cazul unor precipitații abundente ce ar duce la revărsări ale râului Mata Allo. Morfometria râului, utilizarea terenurilor și comportamentul hidrologic din cadrul bazinului hidrografic sunt într-o strânsă relație cu valorile ITU.

Cuvinte-cheie: *modelare, hidrodinamică, atenuare, inundație, bazin de recepție, morfometrie*

Introduction

Global climate change causes extreme rains and floods. Floods have become a serious threat in several countries in the world, especially in Indonesia over the last few decades. The ratio of the occurrence of this disaster is increasing due to high urbanization and continuous development around the river (Chang et al., 2014). The Mata Allo watershed contains residential areas located on the banks of the river which are prone to be affected in the event of a flood. The Mata Allo watershed, which is dominated by hills and mountains with high rainfall, has the potential for flooding in the watershed area (Enrekang Regency Regional Disaster Management Agency, 2021). 57.18% of the Mata Allo watershed is agricultural land, this will trigger flooding during the rainy season, which in general agricultural land is located on a slope of 15-25%. All areas on the earth's surface close to settlements, agriculture, and industry, there is a need for future projections of flood risk to improve the possible mitigation actions (Tramblay et al., 2014).

Due to the concurrent effects of climate change, human activities, land use, and hydrological problems, it is unavoidable and must be addressed in flood risk evaluation (Zhang, 2014). The risk of flooding is defined as a function of both the probability of a flood happening and its impact (Fernández & Lutz, 2010). Floods can cause death and loss of property. High rainfall lasting for a long time can trigger major floods (Sholihah et al., 2020). High-strength floods can cause damage to settlements, agricultural land, road infrastructure, bridges, and human deaths (Carrivick, 2006; Kelley & Prabowo, 2019). The identification, mapping, and zoning of flood-prone areas are critical, becoming more challenging and pressing for our society (Grimaldi et al., 2013). Flood inundation modelling in watersheds and urban areas is important for mitigation and development planning (Chen et al., 2009; Cea & Costabile, 2022). Modeling inundation areas by utilizing Geographic Information Systems (GIS) will be easier to carry out. Flood analysis is due to utilizing spatial data that includes spatial, environmental or regional concepts (Mitchell et al., 2002). So that in estimating areas that have the potential to experience flooding will be easier. The use of GIS is very beneficial in modeling flood events because the input data entered is geographically oriented so that the model formed is not much different from the real model in the field (Vogiatzakis, 2003). Floods that occur in an area are strongly influenced by the duration of the rain, the distribution of rainfall, the topography of the watershed, and land use (Zoccatelli et al., 2010). Changes in the use of forest land to agricultural land will increase by 7% of surface runoff when it rains (Choi, 2007; Guzha et al., 2018). The Mata Allo Watershed (DAS) is an area that often experiences flooding. One of the efforts to anticipate future flood events can be done by identifying and mapping areas that are potentially affected by flooding. This study aims to identify potential flood hazards based on the Topographic Wetness Index (TWI) approach in the Mata Allo watershed. TWI can be used as an indicator to determine potential flood areas so that it can be used as a reference for further regional management.

Study Area

The Saddang and Mata Allo watersheds are located in the central part of South Sulawesi. The total area of the Mata Allo watershed is 923,090 km2. Located at 3° 14' 36″ S to 3° 50' 00″ S and 119° 40' 53″ E to 120° 06' 33″ E (Fig. 1). The area of Enrekang Regency has a tropical climate with air temperatures ranging from 21°–32°C. The relative humidity level ranges from 77% to 83%. Rainfall in the Mata Allo watershed tends to be high throughout the year, ranging from 2,300–2,900 mm/year with the number of rainy days ranging from 160 to 220 rainy days/year. Geomorphology in general, the Mata Allo watershed consists of hilly, mountainous, and karst topographic areas.

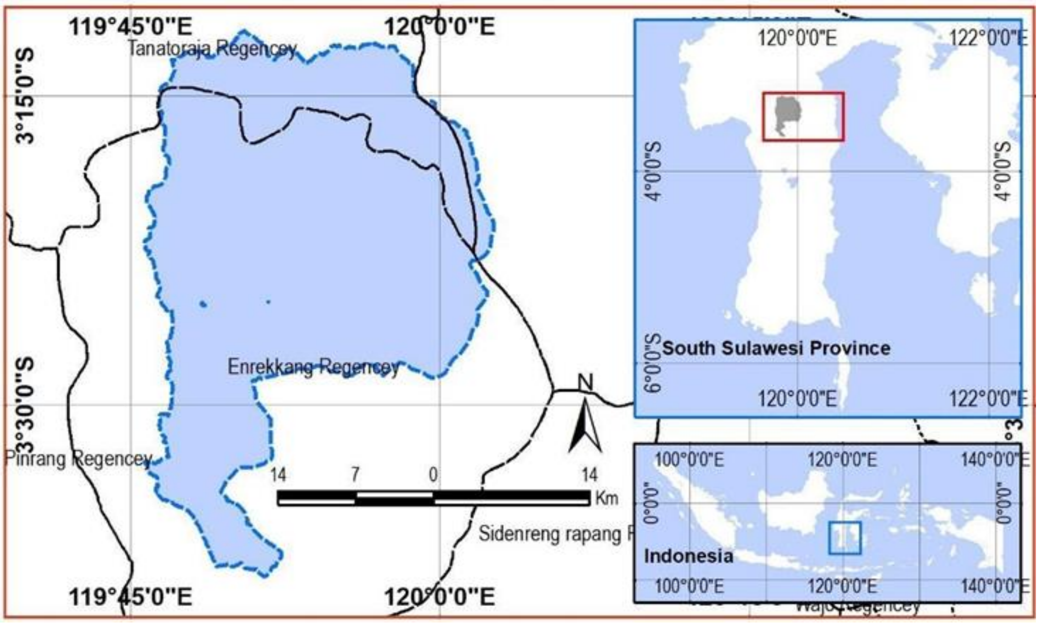


Fig. 1: Research Location Map

The hilly area extends from north to south, with an altitude between 200-1000 meters above sea level. The mountainous area is in the east with an altitude of more than 1000 meters above sea level. While the karst topography is in the middle of Mata Allo watershed. The geology of the study area is composed of a Latimojong formation consisting of shale, filling, chert, marble, quartzite, and quartz which is intruded by medium to alkaline igneous rocks with a formation thickness of more than 1000 meters, which is estimated to be limestone age. The western part consists of reef limestone, marl, conglomerate, shale which is part of the Toraja formation. The land use/land cover consists of settlements, shrubs, primary forest, secondary forest, dryland agriculture, savanna/grassland, rice fields, open land, mixed gardens. and forest. The Mata Allo watershed is dominated by hilly and mountainous topography. On the other hand, there are alluvial plains and flood plains along the edge of a river.

Method

Data used in this study consisted of land use/land cover, geological, geomorphology, slopes, soil types and watershed morphometry. Land use data were obtained from the Regional Development Agency of Enrekang Regency. Geological and Geomorphology data obtained from Geological and geomorphology maps with a scale of 1:50,000. For rainfall and soil type data obtained from the Department of Agriculture, Enrekang Regency.

All data is then processed in ArcGIS to make it a single data unit. To generate morphometric data, Digital Elevation Model (DEM) data is used, obtained from the official website of Indonesia: http://tides.big.go.id/DEMNAS. This DEM data has a resolution of 0.27 arcsecond or 8.3m, making it suitable for use for 50,000 scale map data after resampling. DEM data is used to create slope and elevation data and it is also used for defining sub-watershed boundaries, parameter areas, linear parameters, drainage network characteristics, and relief parameters. The collected data is then presented spatially for later analysis using a mapping application.

Topographic Wetness Index (TWI) is calculated using Digital Elevation Model data processed using ArcGIS 10.4 software. The Topographic Wetness Index is used to determine the condition of the groundwater table and was calculated using the following formula (Beven & Kirkby, 1979);

$$\mathrm{TWI} = \ln(\alpha/\tan\beta)$$

where α is the upslope contributing area per unit contour length and tan β is the slope. Then the TWI results are used to form a prone area inundation class based on the values formed. Formula for the calculation in obtaining TWI which is applied to the data that has been prepared can be seen in the following table (Table 1, 2, 3).

Table 1 Formula used for the computation of Areal Parameters

No.	Parameters	Formula	Definition	Units	References
1	Form Factor (S_b)	$R_f = \frac{A}{L^2b}$	A/Lb^2	Dimensionless	Horton (1945)
2	Shape Factor (S_b)	$S_b=L^2{}_{b/A}$	L=Basin Length (km), A=Area of the basin (km^2)	Dimensionless	Horton (1945)
4	Circulatory Index (I_c)	$I_c = \frac{A}{Ac} = \frac{4\pi A}{P^2}$	A = Area of the basin (km^2), A_c= Area of the circle having equal perimeters as that of drainage basin (km^2)	Dimensionless	Miller (1953), Strahler (1964)
5	Compactness Coefficient (C_c)	$C_c= \frac{P}{2\sqrt{\pi A}}$	Perimeter/Perimeter of Circle of Watershed	Dimensionless	Gravelius (1914)
6	Elongation Ratio (R_e)	$R_e=\left(\frac{Dc}{Lb}\right)= \left(\frac{2}{Lb}\right)\sqrt{\frac{A}{\pi}}$	D_c = Diameter of the circle having the same area as that of the basin (km), Lb = basin length (km)	Dimensionless	Schumm (1956)
7	Texture Ratio (R_t)	$R_t = \frac{N_2}{P}$	N_1 = number of first order streams and P = Basin Perimeter (km)	km^{-1}	Horton (1945)
8	Drainage Density (D_d)	Dd=(∑Lt)/A	ΣLt/A, where ΣLt is the total length of all the ordered streams 1/2Dd	Km/km^2	Horton (1932, 1945)
9	Stream Frequency (F_s)	$F_u = \left(\frac{N}{A}\right)$	N=total number of stream segments of all orders, A=basin area (km^2)	km^{-1}	Horton (1932, 1945)

Table 2 Formula used for the computation of Linear Parameters

No.	Parameters	Formula	Definition	Units	References
1	Stream Order	-	Hierarchical Rank	Dimensionless	Strahler (1964)
2	Basin Length (L_b)	-	Maximum Length Of The Basin measured from the outlet	km	Schumm (1956)
3	Average Basin Width (B)	$B = \left(\frac{A}{L_b}\right)$	A=basin area (km^2) and L_b=basin length	km	-
4	Bifurcation Ratio (R_b)	$R_b = \left(\frac{N_u}{N_{u+1}}\right)$	N_u=Number of stream segments of next higher order u+1	Dimensionless	Schumm (1956)
5	Stream Length (L_u)		Length of the stream	km	Horton (1945)
6	Stream Length Ratio (R_L)	$R_L = \frac{L_u}{L_{u-1}}$	L_u=average length of stream of order u L_{u-1}=average length of stream of order u-1	Dimensionless	Horton (1945)
7	Length of Overland Flow (L_o)	$L_o = \frac{1}{2D_d}$	L_o=length of overland flow D_d=drainage density (km/km^2)	Km	Horton (1945)

Table 3 Formula used for the Computation of Relief Parameters

No.	Parameters	Formula	Definition	Units	References
1	Watershed Relief (H)	$H = Hh - Hl$	The elevation difference between the highest and the lowest point	M	Strahler (1952)
2	Relative relief (R_R)	$= R_R \times 100$	R_R=Relative relief (%) H= Watershed relief (m) and L_p=Length of the perimeter (m)	%	Melton (1957)
3	Relief ratio (R_r)	$R_r = \left(\frac{H}{L_b}\right)$	H=Watershed relief (m) and L_b=basin length (m)	Dimensionless	Schumm (1956)
4	Ruggedness number (R_R)	$R_n = HxD_d$	H = Watershed relief (km) and D_d= drainage density (km/km^2)	Dimensionless	Schumm (1956)
5	Geometric number	Geometric number $= \frac{HxD_d}{S_g}$	H= watershed relief (km) D_d= drainage density (km/km^2) S_gSlope of ground surface (sg=2.H.Dd)	Dimensionless	Suresh (2012)

Overall analysis was carried out using ArcMap software by inputting data on each attribute table on each research variable. The flow of work and analysis carried out in this research can be briefly presented in the form of a research flow diagram as follows. Where a, is the local upslope area draining through a certain point per unit contour length and β is the local slope.

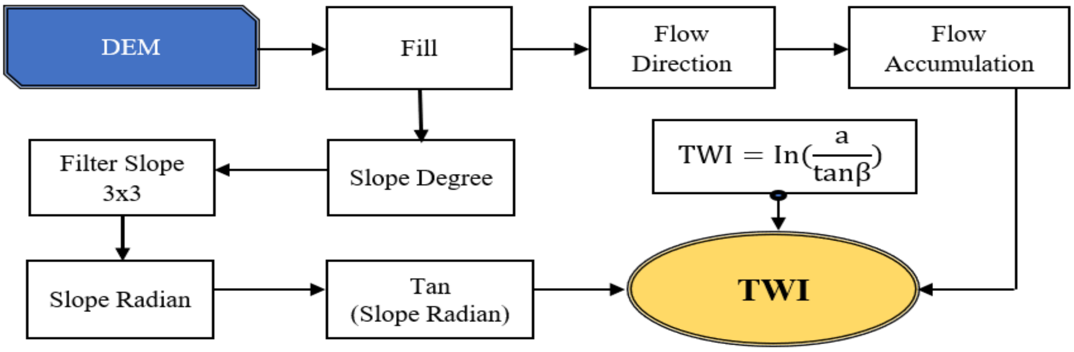


Fig. 2: Analysis Flow Chart

Results and Discussions

Basic Data Analysis

Figures 4, 5 and 6 show the basic maps used as the basis for data analysis. Spatial data used in the form of geological data, geomorphology, soil type, slope, land use land cover, and sub-watershed. Some data such as geological data, geomorphology, soil types are obtained from agencies such as the Ministry of Environment and Forestry and the Geospatial Information Agency. Other data such as slope and subdas data obtained from the results of DEM analysis (Cheah et al., 2019).

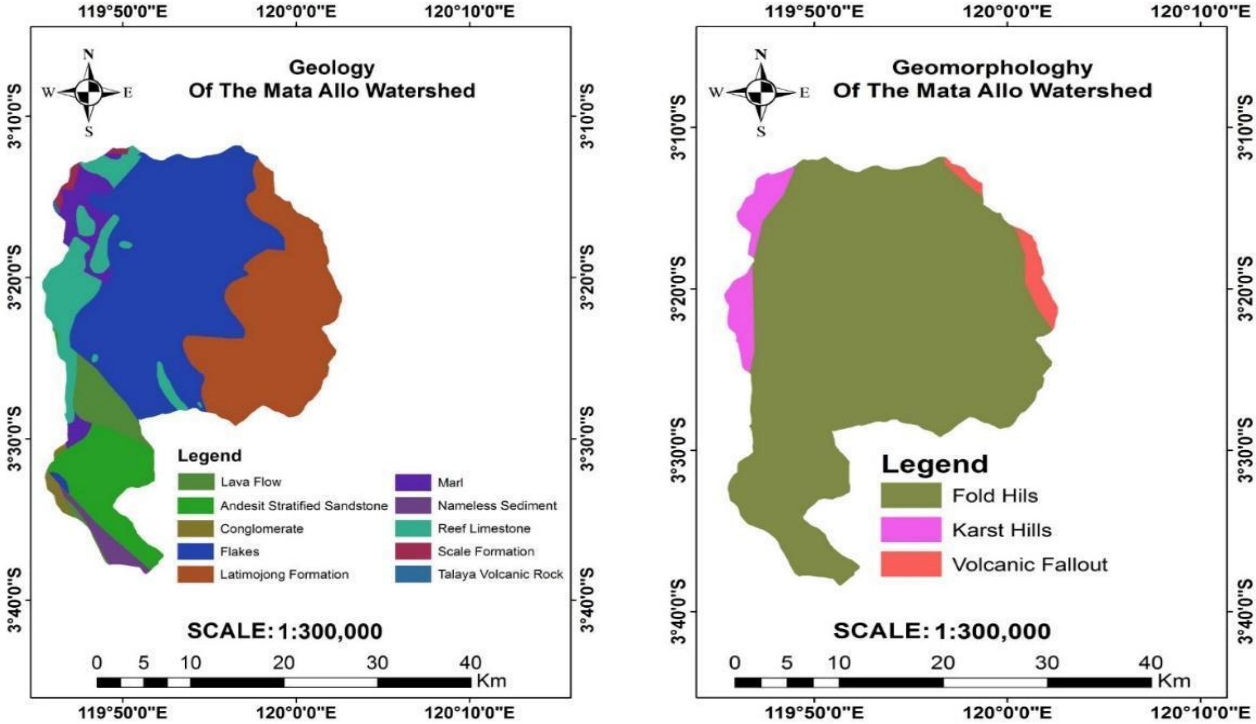


Fig. 3: Geology (left) and Geomorphology (right) map of Mata Allo Watershed

Watershed Area (A)

The area of the Mata Allo watershed is divided into 19 segments. The division of each sub-watershed (SW) is created using ArcGIS 10.4. The total area of the Mata Allo watershed is 923,090 km2, which is included in the large watershed category because it is more than 100 km2 (Horton, 1945). For the analysis of morphometric characteristics, the Mata Allo watershed is divided into 19 sub-watersheds. The area of each sub-basin is between 7,200 km2 – 179.579 km2. The area of the watershed based on slope and land use can be seen in the Table 4-5.

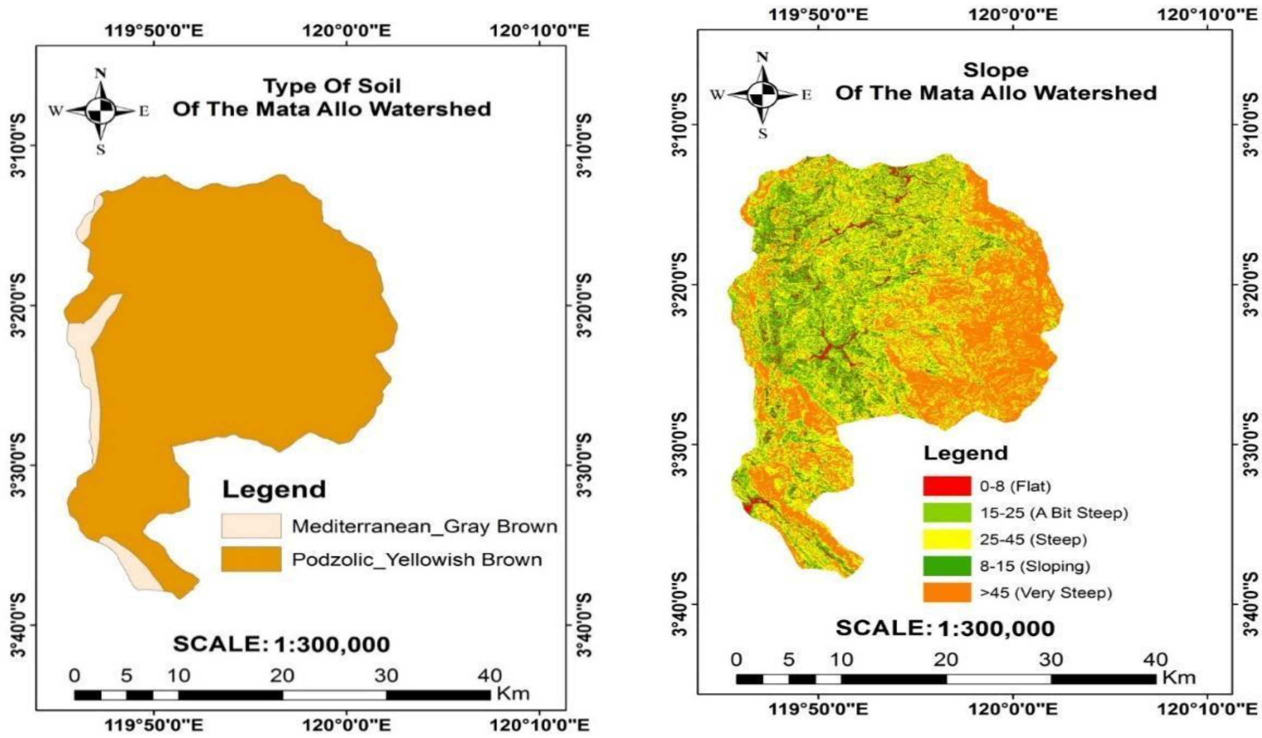


Fig. 4: Soil Type (left) and Slope Class (right) map of Matta Allo Watershed

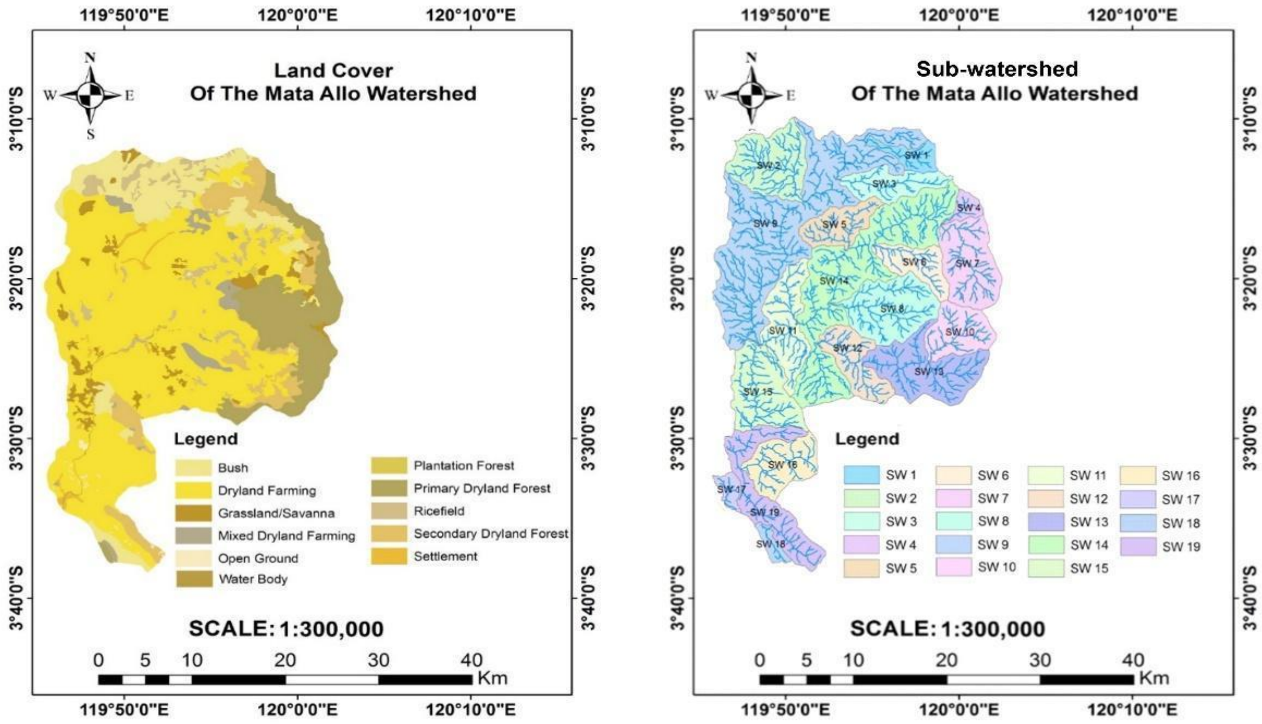


Fig. 5: LULC (left) and Sub-watershed (right) map of Matta Allo Watershed

Stream Length (Lu)

The stream length is hence an indicator of the relationship between vegetation, climate, physical properties of rock, and intensity of soil erosion (Bajabaa et al., 2013). The total length of order 1 to order five of the 19 sub-watersheds is 1460.11 km. Based on the data, the total length of each suborder is almost 2 times greater than the length of the order one level lower. Trendline analysis using logarithmic, between the order level and the total length of the suborder stream, the value of R2 (coefficient of determination) = 0.9784, r (coefficient of correlation) = 0.881.

Using $y=-485 \ln(x)+757.81$ ………………………… (1).

The correlation coefficient value shows that the order level and the total length have a very significant relationship (0.88), with a coefficient of determination of 0.97. A complete table regarding the length of rivers can be seen in Appendix 5-6.

Table 4 The slope of Mata Allo Watershed

No.	Slope	Area (km2)	%
1	0-8	40.56	0.04
2	8-15	97.53	0.10
3	15-25	192.44	0.20
4	25-45	313.60	0.33
5	>45	302.03	0.32

Table 5. Landuse of Mata Allo Watershed

No.	Land Use	Area (ha)	%
1	Waterbody	205	0.21
2	Primary dryland forest	12,201	12.79
3	Secondary dryland forest	7,466	7.83
4	Plantation Forest	106	0.11
5	Settlement	711	0.75
6	Open ground	127	0.13
7	Savanna/grassland	3,712	3.89
8	Dryland farming	54,071	56.70
9	Mixed dry land farming	2,366	2.48
10	Scrub	10,961	11.49
11	Rice Field	3,439	3.61

Drainage Texture (Dt) and Drainage Density (Dd)

The distance between streams is an important geomorphological aspect. Drainage texture for the 19 Mata Allo subbasin is influenced by rock type, rock weathering level, rainfall, temperature, vegetation, soil type, relief, infiltration capacity, and weathering depth of rock and soil solum depth. Land use, its types, and density also play an important role in determining the drainage texture (Kale and Gupta, 2001; Kopecký et al., 2021).

For 19 sub-basin Mata Allo all values of drainage density are included in low (<2). Low drainage density in the Mata Allo watershed indicates highly permeable subsoil material. Based on geology, Mata Allo watershed is dominated by igneous rock and sediment. For more details on the characteristics of Drainage Texture and Drainage Density of watershed, see the table in the Table below.

Table 6. Classification drainage density and drainage texture Mata Allo Watershed

No.	Drainage density (Km/Km^2)	Drainage texture
1	< 2	Very course
2	2 - 4	Course
3	4 - 6	Moderate
4	6 – 8	Fine
5	>8	Very fine

Form Factors (f) and Shape Factors (Sf)

Form factor indicates the flood formation, degree of erosion, and transport capacities of sediment load in a watershed. The shape factor affects the time of increasing and decreasing peak discharge when it rains. The value of form factor for 19 sub-watershed the all between 0.154-0.569. It shows all basin shapes elongated to slightly rounded.

Mata Allo's subwatershed form factors which are very long are SW1, SW3, SW9, SW11, SW14 (very long). The hydrological response to this form is the peak discharge time and the long lag time. This also occurs in SW17 and SW18 (elongated) which have long peak discharge hydrological response characteristics. While SW2, SW7, SW10, and SW16 have a response time of reaching peak discharge and faster lag time. The response of the basin to overland flow, surface runoff, peak flow, lag time, flood during and after rainfall is influenced by the shape factor. The circular basin has the response after rainfall. The Complete table of Form factors and Shape Factors of Mata Allo watershed can be seen in Table below.

Table 7. Classification form factor and shape of Watershed

No.	Form Factor	Shape of Basin
1	< 0.22	Very long
2	0.22 – 0.30	Elongated
3	0.30 – 0.37	Slightly elongated
4	0.37 – 0.45	Neither elongated nor widened
5	0.45 – 0.60	Slightly widened
6	0.60 – 0.80	Widened
7	0.80 – 1.20	Very widened
8	>1.20	Surrounding the drain

Length Overland Flow (lo)

Form The length of overland flow can be defined as the length of the flow of water over the ground before it becomes concentrated in definite stream channels (Singh, 1989). The average length of overland flow ((Lo)) is approximately half the average distance between stream channels (Horton, 1932). The length overland flows its categorization into 3 groups namely: low (< 0.2), moderate (0.2 - 0.3) and high (> 0.3). All sub-basin of Mata Allo (SW1 – SW19) belong to the high category (0.61-0.91). This shows that the Mata Allo sub-basin has the characteristics of a gentle slope, long flow path, more infiltration, and reduced runoff. More details can be seen in the Appendix 1.

Circularity Ratio (Rc)

In Mata Allo's subwatershed, the Rc value varies between 0.149 – 0.717. Low values occur in SW9, SW14, and SW19 (0.149, 0.172, and 0.185), this indicates that the influence of geological and geomorphological structures is low. While high Rc values are found in SW7 and SW10 (Rc values are 0.717 and 0.681, respectively), this indicates that the area is strongly influenced by geological structures. Meanwhile, SW1, Sw2, SW3, SW4, Sw5, Sw6, SW8, SW11, SW12, and SW13 were only slightly influenced by geological and geomorphological structures (Strahler, 1964). More details can be seen in the Appendix 2.

Elongation Ratio (Re)

Schumm (1956), suggested that the shape of a drainage basin be described in the same manner as the shape of rock grain by using the Wadell sphericity ratio. The Re ratio generally varies between 0.60 to 1.0 (Singh, 1989). The ratio of all sub-watershed Mata All0 varies from 0.44 to 0.87. Based on Re Mata Allo Watershed of strong relief and steep ground slopes. The Re shows an increase in elongation with increasing drainage area. Smaller values mean the watershed is elongated. Shows more elongation and is more susceptible to erosion and sediment loads with a smaller infiltration capacity. This happened to SW3, SW9, SW14, and SW19. More details can be seen in the Appendix 2.

Ruggedness Number (Rn)

Rn values are low at SW17 and SW 18 (0.75 and 0.59). This shows a relatively flat basin area. In these areas, the drainage density is relatively lower and less susceptible to erosion, and tends to deposition. Rn values are moderate at SW5, SW11, and SW16 (1.04, 1.83, and 1.77). This subwatershed shows a hilly area with a moderate slope. Meanwhile, SW7, SW13, and SW14 have high scores (3.52, 3.86, and 3.64). This indicates an area whose topography is steep. Very susceptible to erosion, thin soil thickness, and low TWI value. More details can be seen in the Appendix 1.

Compactness Coefficient (Cc)

This is the ratio between the circumference of the basin with the circumference of a circle to the area of the same watershed (Horton, 1945). Cc is independent of watershed size and only depends on slope. The cohesiveness coefficient is directly proportional to the erosion risk assessment i.e. lower values imply less vulnerability to risk factors, while higher values indicate greater vulnerability and represent the need for implementing conservation measures. Lower values of this parameter indicate more basin elongation and less erosion, while higher values indicate less elongation and high erosion (Patel et al., 2012). More details can be seen in the Appendix 2.

Stream Frequency (Fs)

Stream Frequency may be directly related to the solum depth of soil, rock weathering rate, and intensity of soil erosion. It mainly depends upon the lithology of the watershed and reflects the texture of the drainage network. Horton (1945) states that the total number of stream segments of all orders per unit area is the stream frequency. The stream frequency for the all sub-watershed Mata Allo is 2.19 – 3.16, with an average of 2.67. The high Fs is 3.16 on SW5, due to the predominantly agricultural area. In agricultural land, the stream has a high frequency, because land processing activities facilitate erosion, as the initial process of channel formation. While in SW12 the lowest is 2.19 because the area is forest. In the subwatershed that has a high channel frequency, it will accelerate the accumulation of surface runoff into the channel, thereby accelerating the occurrence of peak discharge and vice versa. If the drainage density and relief are high and the slope is steep and long then the ruggedness number is also high (Strahler, 1956; Waikar & Nilawar, 2014). More details can be seen in the Appendix 2.

Relief Ratio

The relief ratio is an indicator of the intensity of the erosion process and solute transport, suspended sediment, and bedload. Relief ratio values are low in SW5, SW9, SW11, SW14, and SW18. A lower Re value indicates the presence of bedrock that is resistant to weathering, forming small hills and low slopes. While the high relief ratio values are found in the subwatershed in SW4 and SW10, these results indicate that in these areas there are strong erosion processes, the bedrock is relatively easily weathered, while the other subwatershed are categorized as moderate values. The relief ratio is also important in assessing floods, especially in hydrological and physiographic control.

The Topographical wettability index (TWI) is the steady-state wettability index. It is commonly used to measure the topographical control of hydrological processes. The index is a function of the slope and upstream area that contributes per unit width orthogonal to the flow direction. The index is designed for hillside catenas. The amount of accumulation in flat areas will be very large, so TWI will not be a relevant variable. The index is highly correlated with several soil attributes such as horizon depth, silt percentage, organic matter content, and phosphorus. The method of calculating this index differs mainly in how to calculate the contribution area of the upslope. Soils formed on alluvial plains from exogenous energy processes include temperature, rainfall, topography, and rock types.

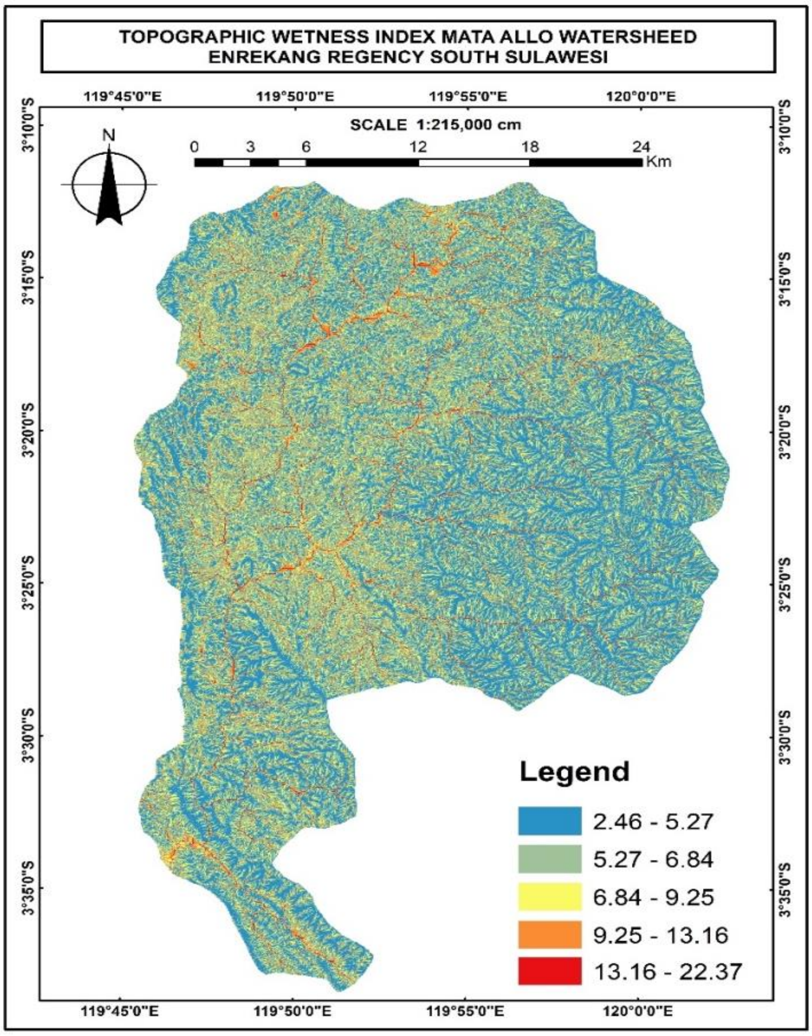


Fig. 6: TWI Map of Mata Allo Watershed

The alluvial plain in the Mata Allo watershed occupies the area between the mountain and the river valley plain, whose material comes from the upstream or upper part of the slope. The groundwater potential in the Mata Allo watershed on alluvial plains is higher so that the moisture index is higher than the soil on the steep slopes. The polar nature of water results in the attraction of water molecules for each other (cohesion) and the attraction of water for other surfaces, such as clay (adhesion). Adhesion and cohesion are important because, among other things, they provide the soil with the ability to store water. The capillarity that water will move up into the tube, can increase the wetness of soil on the surface (McLaren & Cameron, 2004). The movement of water on the slopes of the Mata Allo watershed is strongly influenced by the total potential energy of the water. The potential energy of gravity is high on steep slopes (low TWI values), indicating that the movement of water will always go to the flat lower slope (high). The TWI index is reliable information to the public about the flood risk to identify future flood-prone areas (Cook & Merwade, 2009). TWI is one of the factors that show the potential for accumulation of surface run-off, intermediate flow, and baseflow.

Table 8 Area of TWI Mata Allo Watershed

No.	TWI	Inundation Susceptibility Level	Area (Km^2)
1	2.46 - 5.27	Very Low Inundation Susceptibility	366.79
2	5.27 - 6.84	Low Inundation Susceptibility	363.68
3	6.84 - 9.25	Moderate Inundation Susceptibility	144.78
4	9.25 - 13.16	High Inundation Susceptibility	57.30
5	13.16 - 22.37	Very High Inundation Hazard	13.63

The higher the TWI value, the higher the occurrence of runoff, so it can be used as a quick method for identifying flood-prone areas. The amount of accumulated water flow in flat areas is higher than on steep slopes. TWI is highly correlated with several soil attributes such as the depth of the soil horizon, the percentage of dust, and the content of organic matter (Sørensen et al., 2006; Schoonover & Crim, 2015). Soil that has a high organic matter content, can bind water well. high because it has a high outer charge, as well as soils containing clay and dust, have high water-binding abilities, and are difficult to release water because the bond between water and soil is very strong because it is dominated by micropores and the surface charge on clay and dust is high.

TWI in the Mata Allo watershed, in response to earth's gravity (Pourali et al., 2014). This is related to the high TWI value of the Mata Allo River which is spread around the alluvial plains around the riverbanks and the alluvial plains between the mountains. This is also related to the condition of alluvial plains where the material has a relatively coarse texture, has many macropores, so the effect of gravitational potential is higher, compared to the effect of the matrix potential. The highest TWI value is 13.16 - 22.37 with a percentage of 1.44% (13.63) km^2. In 2021, agricultural land use in the Mata Allo Watershed which has reached 59.18% will increase the amount of runoff. Research in the Richland Creek Basin (Illinois, USA) shows that land-use change increases the average annual runoff by 7% (Choi, 2007; Hu & Shrestha, 2020). By knowing the distribution of TWI values in the study area, in this case the watershed. So the priority areas for efforts to avoid and prevent losses due to flood disasters can be done earlier. The resulting data can then be utilized by the local government, especially by the Regional Disaster Management Planning Agency. TWI which shows areas that are most likely to experience inundation due to surface runoff. spatially, regional development planning can be carried out in tackling and anticipating disaster events such as floods.

Conclusion

The Mata Allo watershed is elongated. The morphometric characteristics that have a response to rain are peak discharge and lag time which take a long time to achieve. The slope of the slope is 25→45%, the area is 65%, this triggers the velocity of surface flow, intermediate flow, and base flow to the bottom of the slope due to the influence of gravitational potential energy. Likewise, the change in forest land use to agriculture has reached 59.18%, which will increase surface runoff, erosion on the upper slopes and upstream of the river, while on the plains in the area between the mountains and the riverbanks there will be sedimentation in the Mata Allo watershed. Increased erosion and deposition processes will thicken the sedimentary material which will become the parent material for soil formation. Sedimentary material that’s mixed between coarse and clay materials will increase the ability to bind and store groundwater. The ability to bind and store groundwater (aquifer) will increase the value of soil moisture. Soil that has high humidity will reduce the infiltration capacity so that if the rainfall intensity is higher than the infiltration capacity, there will be inundation. Thus the area in the Mata Allo watershed that has a high TWI value has a risk of inundation when it rains (13.63 km2).

Funding

This research was funded by Ministry of Education, Culture, Research and Technology, Indonesia, 2022 Number: 033/E5/PG.02.00.PT.2022.

Acknowledgements

Thanks to Makassar State University for providing the opportunity to carry out this research. Along with Makassar State University Geography students who have assisted in data processing.

Author Contribution

Designing research concepts, U.; data processing and article writing, N.A.H.; formulation and interpretation of research results, M.L., and S.N. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Bajabaa, S., Masoud, M., & Al-Amri, N. (2013). Flash Flood Hazard Mapping Based on Quantitative Hydrology, Geomorphology and GIS Techniques (Case Study of Wadi Al Lith, Saudi Arabia). *Arab Journal of Geosciences*, 7, 2469-2481. https://doi.org/10.1007/s12517-013-0941-2

Beven, K.J., & Kirkby, M.J. (1979). A Physically Based, Variable Contributing Area Model Of Basin Hydrology. *Hydrological Science Bulletin*, 24 (1), 43–69. https://doi.org/10.1080/02626667909491834

Bisht, S., Chaudhry, S., Sharma, S., & Son, S. (2018). Assessment Of Flash Food Vulnerability Zonation Through Geospatial Technique in High Altitude Himalayan Watershed. *Remote sensing Applications: Society and Environment*, 12, 35-47.

Cea, L., & Costabile, P. (2022). Flood Risk in Urban Areas: Modelling, Management and Adaptation to Climate Change: A Review. *Hydrology*, 9(3). https://doi.org/10.3390/hydrology9030050

Chang, L., Shen, H.Y., & Chang, F.J. (2014). Regional flood inundation nowcast using hybrid SOM and dynamic neural networks. *Journal of Hydrology*, 519, 476–489. https://doi.org/10.1016/j.jhydrol.2014.07.036

Cheah, R., Billa, L., Chan, A., Teo, F. Y., Pradhan, B., & Alamri, A. M. (2019). Geospatial modelling of watershed peak flood discharge in Selangor, Malaysia. *Water* (Switzerland), 11(12), 1–12. https://doi.org/10.3390/w11122490

Chen, J., Hill, A., & Urbano, L.D. (2009). A GIS-based model for urban flood inundation. *Journal of Hydrology*, 373, 184–192. https://doi.org/10.1016/j.jhydrol.2009.04.021

Choi, W. (2007). Estimating Land Use Change Impacts on Direct Runoff and nonpoint Source Pollutant Loads in the Richland Creek Basin Illinois USA by Applying the Long-Term Hydrologic Impact Assessment. *Journal of Spatial Hydrology*, 7 (1),47-65. https://scholarsarchive.byu.edu/josh/vol7/iss1/3

Cook, A., & Merwade, V. (2009). Effect of topographic data, geometric configuration, and modeling approach on flood inundation mapping. *Journal of Hydrology*, 377, 131–142. https://doi.org/10.1016/j.jhydrol.2009.08.015

Carrivick, J.L. (2006). Application of 2D hydrodynamic modeling to high-magnitude outburst floods: An example from Kverkfjoll, Iceland. *Journal of Hydrology*, 321, 187–199.

Zoccatelli, D., Borga, M., Viglione, A., Chirico, G.B., & Bloschl, G. (2010). Spatial moments of catchment rainfall: rainfall spatial organization, basin morphology, and flood response. *Hydrol. Earth System Science Discuss.*, 8: 5811–5847. http://dx.doi.org/10.5194/hess-15-3767-2011

Fernández, S., & Lutz, M.A. (2010). Urban Flood Hazard Zoning In Tucumán Province, Argentina, Using GIS And Multicriteria Decision Analysis. *Engineering Geologi*, 111, 90-98. https://doi.org/10.1016/j.enggeo.2009.12.006

Gravelius, H. (1914). Grundrifi der gesamten Gewässerkunde. Band I: Flufikunde (Compendium of Hydrology, Vol. I. Rivers, in German). Berlin: Goschen

Grimaldi, S., Petroselli, A., Arcangeletti, E., & Nardi, F. (2013). Flood mapping in ungauged basins using fully continuous hydrologic–hydraulic modeling. *Journal of Hydrology,* 487, 39–47. https://doi.org/10.1016/j.jhydrol.2013.02.023

Guzha, A.C., Rufino, M.C., Okoth, S., Jacobs, S., & Nóbrega, R.L.B. (2018). Impacts of land use and land cover change on surface runoff, discharge and low flows: Evidence from East Africa. *Journal of Hydrology: Regional Studies*, 15,49–67. https://doi.org/10.1016/j.ejrh.2017.11.005

Horton, R.E. (1932). Drainage-Basin Characteristics. Eos, Trans Am Geophys Union, 13(1), 350–361. https://doi.org/10.1029/TR013i001p00350

Horton, R.E. (1945). Erosional Development of Streams and their Drainage Basins. *Hydrophysical Approach to Quantitative Morphology*. GSA Bull, 56(3), 275–370. https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Hu, S., & Shrestha, P. (2020). Examine the impact of land use and land cover changes on peak discharges of a watershed in the midwestern United States using the HEC-HMS model. *Papers in Applied Geography*, 6(2), 101–118. https://doi.org/10.1080/23754931.2020.1732447

Jasmin, I., & Mallikarjuna, P. (2013). Morphometric analysis of Araniar river basin using remote sensing and geographical information system in the assessment of groundwater potential. *Arab J Geosci*, 6, 3683–3692. http://dx.doi.org/10.1007/s12517-012-0627-1

Jonathan, W.F., Remo, A.B., Nicholas, Pinter A.B., & Reuben Heine, C. (2009). The Use Of Retro- And Scenario-Modeling To Assess Effects Of 100+ Years River Of Engineering And Land-Cover Change On Middle And Lower Mississippi River Flood Stages. *Journal of Hydrology*, 376, 403–416.

Kale, V.S., & Gupta, A. (2001). Introduction to geomorphology. New Delhi: Academic.

Kelley, L.C., & Prabowo, A. (2019). Flooding and Land Use Change in Southeast Sulawesi, Indonesia. *Land*, 8(9), 1–19. https://doi.org/10.3390/land8090139

Kopecký, M., Macek, M., & Wild, J. (2021). Topographic Wetness Index calculation guidelines based on measured soil moisture and plant species composition. *Science of the Total Environment*, 757. https://doi.org/10.1016/j.scitotenv.2020.143785

McLaren, R.G., & Cameron, K.C. (2004). Soil Science: Sustainable Production and Environmental Protection. English: Oxford University Press.

Melton, M. (1957). An Analysis of the Relations Among Elements of Climate, Surface Properties and Geomorphology. Department of Geology, Columbia University, Technical Report, 11, Project NR 389-042. Office of Navy Research, New York. https://doi.org/10.7916/d8-0rmg-j112

Miller, V.C. (1953). A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. Department of Geology Columbia University, New York, 389-402. https://doi.org/10.1086/626413

Mitchell, S., Csillag, F., & Tague, C. (2002). Advantages of Open-source GIS to Improve Spatial Environmental Modeling. Proceedings of the Open Sources GIS- …, September, 1–11. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.20.40&rep=rep1&type=pdf

Moore, I.D., Gessler, P.E., Nielsen, G.A., & Petersen, G.A. (1993). Terrain Attributes: Estimation Methods and Scale Effects. In: Jakeman A.J., Beck M.B., McAleer M. (eds.). Modeling Change in Environmental Systems. London: Wiley, 189–214.

Pourali, S.H., Arrowsmith, C., Chrisman, N., Matkan A.A., & Mitchel, D. (2014). Topographic Wetness Index Application in Flood -Risk-Based Land Use Planning, Appl. Spat. *Journal Water*, 1-21(9), 39–54.

https://doi.org/10.1007/s12061-014-9130-2

Quinn, P., Beven, K., Chevallier, P., & Planchon, O. (1991). The Prediction of Hillslope Flow Paths for Distributed Hydrological Modeling Using Digital Terrain Models. *Hydrological Processes*, 5 (1), 59-79.

Schoonover, J. E., & Crim, J. F. (2015). An Introduction to Soil Concepts and the Role of Soils in Watershed Management. *Journal of Contemporary Water Research & Education*, 154(1), 21–47. https://doi.org/10.1111/j.1936-704x.2015.03186.x

Schumm, S.A. (1956). The evolution of drainage systems and slopes in bad lands at Perth, Amboi, New Jersey. *Geol. Soc. Ame. Bull.* 67, (5) 597-646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

Sholihah, Q., Kuncoro, W., Wahyuni, S., Puni Suwandi, S., & Dwi Feditasari, E. (2020). The analysis of the causes of flood disasters and their impacts in the perspective of environmental law. *IOP Conference Series: Earth and Environmental Science*, 437(1). https://doi.org/10.1088/1755-1315/437/1/012056

Singh, V.P. (1989). Hydrologic Systems: Watershed Modeling. Volume II. Englewood Cliffs, New Jersey: Prentice-Hall. ISBN 10: 0134480287

Sørensen, R., Zinko U., & Seibert, J. (2006). On The Calculation of The Topographic Wetness Index: Evaluation of Different Methods Based On Field Observations. *Hydrology and Earth System Sciences*, 10 (1), 101–112. https://doi.org/10.5194/hess-10-101-2006

Strahler, A.N. (1964). Quantitative Geomorphology of Drainage Basin and Channel Networks. McGraw-Hill, New York: Handbook of applied hydrology. DOI: 10.1007/3-540-31060-6_304

Tramblay, Y., Ernest Amoussou, B, C, Wouter Dorigo D., & Gil Mahé, A. (2014). Flood Risk Under Future Climate in Data Sparse Regions: Linking Extreme Value Models and Flood Generating Processes. *Journal of Hydrology*, 519, 549–558. https://doi.org/10.1016/j.jhydrol.2014.07.052

Vogiatzakis, I.N. (2003). GIS-based Modelling and Ecology: A Review of Tools and Methods. *Geographical Paper*, 170(170), 1–34.

Zhang, Q., Xihui, G., Singh, V.P., & Xiao, M. (2014). Flood Frequency Analysis with Consideration of Hydrological Alterations: Changing Properties, Causes, And Implications. *Journal of Hydrology*, 519, 803–813. http://dx.doi.org/10.1016/j.jhydrol.2014.08.011

Appendix

Appendix 1. The value of relief parameters

Parameters	H	Rr	Lo	Rn
SW 1	0.36	0.18	0.76	2.29
SW 2	0.00	0.12	0.91	2.08
SW 3	0.31	0.14	0.73	2.64
SW 4	0.37	0.31	0.70	2.19
SW 5	0.46	0.07	0.79	1.04
SW 6	0.20	0.23	0.73	3.41
SW 7	0.27	0.24	0.70	3.52
SW 8	0.16	0.20	0.80	3.81
SW 9	0.21	0.05	0.85	2.59
SW 10	0.33	0.28	0.74	3.39
SW 11	0.25	0.08	0.80	1.83
SW 12	0.24	0.14	0.80	2.38
SW 13	0.20	0.19	0.75	3.86
SW 14	0.16	0.07	0.83	3.64
SW 15	0.09	0.12	0.82	2.39
SW 16	0.07	0.14	0.72	1.77
SW 17	0.06	0.10	0.70	0.75
SW 18	0.26	0.09	0.61	0.59
SW 19	0.04	0.14	0.71	1.69

Appendix 2. The value of areal parameters

Parameters	Rf	Sb	Rc	Compactness of Coefficient	Re	Rt	Dd	Fs	Constant of Channel Maintenance (Cc)
SW 1	0.20	5.01	0.37	1.65	0.50	0.77	1.52	2.34	0.66
SW 2	0.60	1.68	0.57	1.33	0.87	2.06	1.81	2.67	0.55
SW 3	0.18	5.50	0.35	1.68	0.48	1.41	1.45	3.05	0.69
SW 4	0.33	3.03	0.52	1.39	0.65	0.71	1.40	2.34	0.72
SW 5	0.29	3.42	0.48	1.44	0.61	1.67	1.57	3.16	0.64
SW 6	0.25	3.96	0.45	1.50	0.57	1.26	1.46	2.56	0.68
SW 7	0.48	2.08	0.72	1.18	0.78	2.30	1.40	2.61	0.71
SW 8	0.38	2.61	0.58	1.31	0.70	2.23	1.59	2.74	0.63
SW 9	0.19	5.38	0.15	2.59	0.49	1.99	1.70	2.67	0.59
SW 10	0.51	1.95	0.68	1.21	0.81	2.04	1.47	2.98	0.68
SW 11	0.20	4.98	0.35	1.69	0.51	1.53	1.60	2.66	0.62
SW 12	0.42	2.37	0.35	1.69	0.73	1.28	1.60	2.19	0.62
SW 13	0.32	3.11	0.38	1.62	0.64	1.93	1.50	2.78	0.66
SW 14	0.15	6.48	0.17	2.41	0.44	2.09	1.66	2.93	0.60
SW 15	0.38	2.62	0.56	1.34	0.70	2.26	1.64	2.84	0.61
SW 16	0.50	2.01	0.64	1.25	0.80	1.78	1.44	2.50	0.69
SW 17	0.29	3.40	0.49	1.43	0.61	0.86	1.40	2.99	0.71
SW 18	0.24	4.26	0.46	1.47	0.55	0.64	1.21	2.36	0.83
SW 19	0.18	5.72	0.19	2.33	0.47	1.05	1.42	2.30	0.70

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December 2022**), pp. **146-157**
http://dx.doi.org/**10.5775/fg.2022.192.d**

Covid-19 lockdown effect on aerosol optical depth in Delhi National Capital Region, India

Sharma VIPASHA[1], Ghosh SWAGATA[2,*], SHAHNAWAZ[3], Rai KUMAR PRAVEEN[4], Singh SULTAN[5]

[1] Amity Institute of Geoinformatics and Remote Sensing (AIGIRS), Amity University, Sector 125, Noida-201313, U.P., India
[2] Department of Geography, School of Earth Sciences, Central University of Karnataka, Kadaganchi, Karnataka, India
[3] Department for Geoinformatics–Z_GIS, University of Salzburg, 5020 Salzburg, Austria
[4] Department of Geography, Faculty of Social Sciences, Khwaja Moinuddin Chishti Language University, Lucknow-226013, India
[5] Haryana Space Applications Centre Node, Gurgaon New labour court building, Mini Secretariat, Sector 11, Gurugram, Haryana 122001, India
* *Corresponding author*: swagata.gis@gmail.com; swagataghosh@cuk.ac.in

Received on 15-06-2022, reviewed on 30-20-2022, accepted on 10-12-2022

Abstract

Coronavirus cases in India have been steadily increasing since March 2020. COronaVIrus Disease 2019 (COVID-19) has been managed by a variety of preventative measures. A prominent measure by the Government of India to prevent the spread of Coronavirus Disease 2019 (COVID-19) began on March 25, 2020, with a complete suspension of all outdoor activities throughout the country. Such complete lockdown has resulted in a decrease in anthropogenic emissions, which is partly due to restrictions on human activities. Delhi National Capital Region (NCR), a landlocked area, suffers from high amounts of aerosols due to both natural and anthropogenic sources. The present research focuses on changes in Aerosol Optical Depth (AOD) prior to and during lockdown (initial and second lockdown phases) around satellite cities (Faridabad, Ghaziabad, Gautam Budh Nagar and Gurugram) of Delhi using high-resolution MODIS AOD product. With the implementation of lockdown measures in phase I and phase III of the current study region, AOD decreased dramatically, while phase II and phase IV lockdown phases had a higher concentration of aerosol. An unexpected increase in AOD occurred during the second lockdown compared with the initial lockdown and before the lockdown. Overall, the average percentage change from 2019 to 2020 during first lockdown is -4.44%, while the average percentage change from 2020 to 2021 is 27.63%.

Keywords: *MAIAC, COVID-19, lockdown, satellite cities, aerosol optical depth*

Rezumat. Efectul lockdown-ului din perioada Covid-19 asupra adâncimii optice a aerosolilor în regiunea capitalei naționale Delhi, India

Numărul cazurilor de Coronavirus din India a fost într-o continuă creștere începând cu luna martie 2020. Pentru a face față epidemiei de Covid-19 au fost luate mai multe măsuri preventive. Una dintre cele mai importante măsuri luate de către guvernul Indiei pentru limitarea răspândirii virusului și a bolii a fost luată începând cu 25 martie 2020, și a presupus suspendarea tuturor activităților în aer liber pe tot teritoriul statului indian. O astfel de situație a dus la o diminuare a emisiilor antropice, parțial datorită restricțiilor impuse activităților umane. Regiunea Capitalei Naționale Delhi, o regiune fără ieșire la mare, se confruntă cu o cantitate mare e aerosoli, generată atât de factori naturali, cât și antropici. Lucrarea de față analizează schimbările în Adâncimea Optică a Aerosolilor (AOA înainte și în perioada de lock-down (faza de lockdown inițial și următoarea) în cazul orașelor satelit ale capitalei (Faridabad, Ghaziabad, Gautam Budh Nagar și Gurugram), folosind MODIS AOD de mare rezoluție. O dată cu implementarea măsurilor de lockdown din faza I si III, în aria studiată AOA a scăzut considerabil, în timp ce în fazele II și IV s-a înregistrat o concentrație mai mare de aerosoli. O creștere neașteptată a AOA a fost sesizată în cea de a doua perioadă de lockdown, comparativ cu situația din perioara primului lockdown și cea premergătoare acestuia. Per ansamblu, schimbările medii procentuale din 2019 si 2020 pentru prima perioadă de lockdown au fost de -4,4%, în timp ce pentru a doua perioadă, 2020-2021 de 27.63%.

Cuvinte-cheie: *MAIAC, Covid-19, lockdown, orașe satelit, adâncimea optică a aerosolilor*

Introduction

COronaVIrus Disease 2019 (COVID-19) emerged in December of 2019 and spread rapidly around the world (Suvarna Fadnavis et al., 2021). The meteorological conditions and pollutants favoured the quick outbreak of the COVID-19 pandemic (Jiang et al., 2021; Lolli & Vivone, 2020; Simone, Ying-Chieh, Sheng-Hsiang, & Gemine, 2020) which had caused 3,588,773 cases and 247,503 deaths globally as on 6 May, 2020 (Bedi, Dhaka, Vijay, Aulakh, & Gill, 2020). To control the spread of COVID-19, the lockdown restrictions were enacted in January in China and afterward in other nations worldwide (Chauhan & Singh, 2020; Paital, 2020; Yunus, Masago, & Hijioka, 2020). In China, the USA, Spain, variations in meteorological parameters and a decrease in concentrations of air pollutants have been noted during lockdown (Tobías et al. 2020; Muhammad et al. 2020; Baldasano 2020; Nurshad and Farjana 2020; Sanap 2021). India confirmed its first case of COVID-19 on January 30, 2020, and until May 6, 2020, 49,391 cases and 1,694 deaths were reported (WHO (2020b), 2020). In India, a Janata curfew (Public Curfew) was initiated on 22 March 2020, and then on March 25, 2020, a very tight state-wide lockdown was implemented to stem the spread of the virus, COVID-19 (Chauhan & Singh, 2020; Government of India, 2020). Residents were barred from leaving their houses, and public transportation (railways, roads, and airports), industries, and companies were closed except for essential services. Such COVID-19 pandemic lockdown has an impact on air quality in India.

Prior to lockdown, India had suffered immensely from severe air pollution resulting from recent economic growth, traffic emissions, and land-use changes for decades (World Bank and International report 2020; Fadnavis et al. 2013; Guttikunda et al. 2014; Hama et al. 2020). Such acute pollution resulted in an increase of 2.6 hazy days per year and a death rate of 8.8% (Council & Medical, 2017; IHME, 2019; Thomas, Sarangi, & Kanawade, 2019). India ranked fifth in the world in terms of particulate matter ($PM_{2.5}$). Moreover, India lead the list of the world's smoggiest urban districts, accounting for 21 of the top 30 most polluted cities (WAQR, 2019). Ten of the top 21 polluted cities were in Delhi, National Capital Region (NCR) (World Air Quality Report 2020, 2020). Increasing industrialization, commercialization, and urbanization have all adversely affected the air quality in National Capital Region. Delhi's polycentric growth had led to the proliferation of motorized vehicles and industrial activities in its surrounding areas, viz. Faridabad, Gurugram, Gautam Budh Nagar, and Ghaziabad etc. causing many pollutants (PM, NOx, SOx, NH3, O3) (Garg & Gupta, 2019; Gulia, Nagendra, & Khare, 2017; Kumar, Ghosh, Hooda, & Singh, 2019; Kumar, Ghosh, & Singh, 2022; K. Ranjan, Sharma, & Ghosh, 2022; S. K. Sharma et al., 2014; V. Sharma, Ghosh, Kumari, et al., 2022; V. Sharma, Ghosh, Singh, et al., 2022; S. Singh & Peshin, 2014).

Even with such high levels of pollution, India had also experienced improved air quality during the lockdown since the level of anthropogenic activities have been reduced (Chen, Huang, Yuan, & Tan, 2020; M. Jain, Taubenböck, & Namperumal, 2011; Muhammad et al., 2020; Shukla, Sharma, Baruah, Shukla, & Gargava, 2020; Tobías et al., 2020; Xu et al., 2020). Earlier research have reported the impact of first lockdown phases on air quality measures using wide range of pollutants in India and across the globe (Dantas, Siciliano, França, da Silva, & Arbilla, 2020; Garg & Gupta, 2019; Li et al., 2020; S. Sharma et al., 2020). A significant decline in AOD_{MAIAC} (0.16) throughout the Indian landmass has been reported (Mishra & Rathore, 2021). North India had a 40% decrease in aerosol levels (Suvarna Fadnavis et al., 2021; S. Gautam, 2020; S. Jain & Sharma, 2020, Le Quéré et al., 2020), while over Southern India, the AOD_{MAIAC} levels were increased due to local biomass burning (Le Quéré et al., 2020; Pandey & Vinoj, 2021; Sanap, 2021; T. Singh et al., 2020). As part of the current study area, Gautam Budh Nagar, Gurugram, and Ghaziabad have recorded a 55-65% reduction in PM_{10} and $PM_{2.5}$, and the AQI has improved (Garg & Gupta, 2019).

Effect of first lock down over different parts of India have been examined in various research published earlier (A. S. Gautam et al., 2021; Pathakoti et al., 2021; Pramod, 2021; Rani & Kumar, 2022). However, no study analyzed the spatial-temporal variation of Aerosol Optical Depth (AOD) at a micro-scale during the second lockdown in 2021 for the current study area. Considering the importance of micro-level study for designing the area-specific management plan, present research utilized AOD_{MAIAC}, obtained at high temporal and spatial resolution (daily at 1 km) and compares the percentage of AOD variations from pre-lockdown (2019) to first lockdown (2020) and second lockdown (2021) periods. Further, previously published research highlighted the rise in AOD from pre-lockdown period (from January 2020 to March 2020-winter + pre-monsoon) to first lockdown period (from March 2020 to May 2020-pre-monsoon) to post-lockdown period (from May 2020 to July 2020-pre-monsoon + monsoon). However, such rise in AOD could not be considered as the sole effect of lockdown, as the aerosol concentration could be modified during different seasons because of the influence of climatic parameters (V. Sharma, Ghosh, Bilal, Dey, & Singh, 2021). Therefore, in the present research, to examine the lone effect of lockdown over the variation of AOD, same time frame is used (keeping the season constant) and the variation of AOD has been analysed during lockdown, pre-lockdown, and post-lockdown periods.

Site Description

The present study area, located in the semi-arid climatic zone of India includes parts of Delhi's National Capital Region (NCR), Gautam Buddha Nagar and Ghaziabad of Uttar Pradesh (28.33°N - 77.60°E), Gurugram and Faridabad of Haryana (28.31°N – 77.33°E) (Fig. 1). Since the last decade, these districts of NCR have experienced rapid urbanization and industrialization accompanied by acute air pollution and high temperature (Ghosh, N., Kumar, & Midya, 2021; Kumar, Midya, Ghosh, & Singh, 2021).

In NCR, apart from the natural sources, traffic density, industrial operations, construction works, dust re-suspension, biomass burning, and regional pollution transit are the anthropogenic drivers of particulate matter concentrations ($PM_{2.5}$ and PM_{10}). Ghaziabad was the most polluted city in South Asia, followed by Noida (ranked fifth), Gurugram (ranked sixth), Greater Noida (ranked eighth), and Faridabad (ranked eleventh) (WAQR 2019). This region lacks scientific studies on particle pollution, despite its rapid expansion and high levels of air pollution. Within the current study area, the first lockdown was imposed from 24 March 2020 to 31 May 2020 and the second lockdown was from 5 April, 2021 to 15 June, 2021.

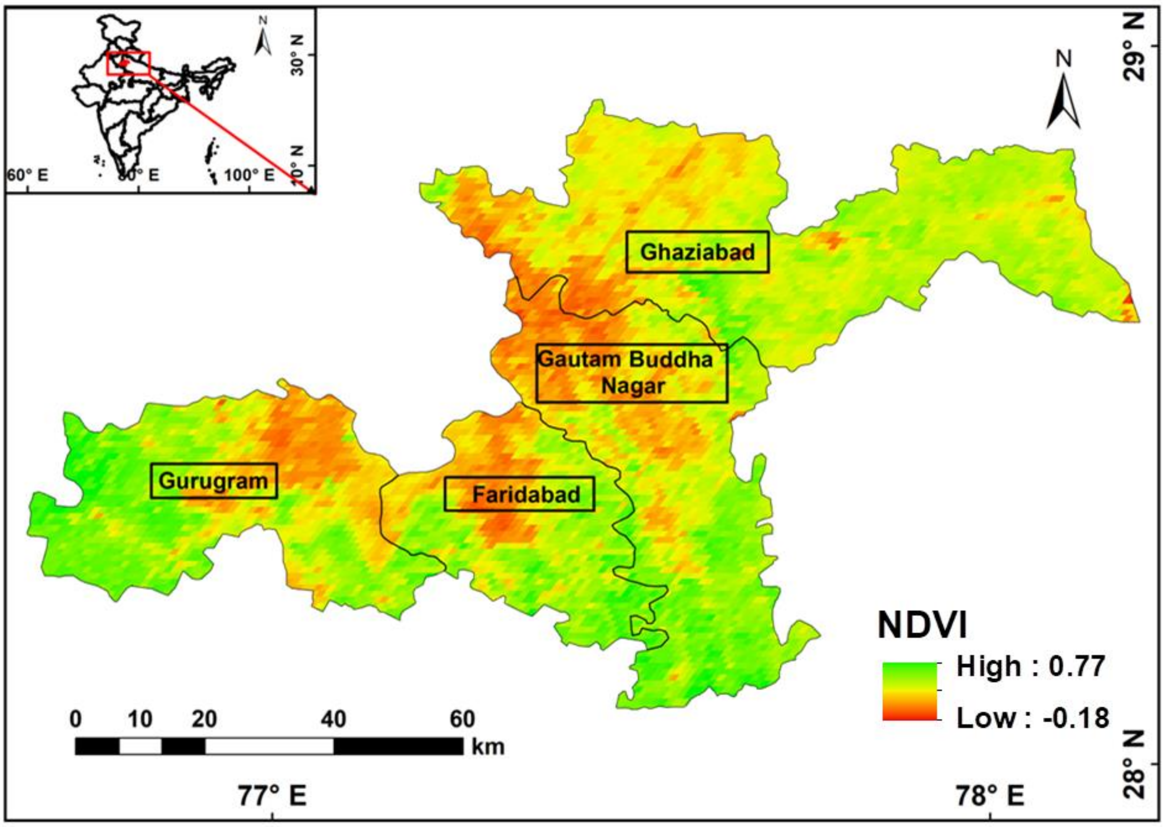


Fig. 1: Study area description shown in MODIS NDVI product (MOD13A2)

Depending on the severity of infection rate and number of COVID cases, all 727 districts across the country were divided into three zones (red, orange, and green). The red zone areas had highest incidence of cases and lockdown was maintained in the red zones. The area where not even a single case reported in last 14 days were categorized as orange zone and only private, hired cars, not public transportation, were permitted in orange zones. Ggreen zone designated the area where no case had been reported in the last 28 days and normal travel was permitted, with buses limited to 50 percent capacity. The Red Zone covered Faridabad, and Gautam Budddha Nagar, the Orange Zone covered Gurugram, and Ghaziabad. Red zones have a high number of coronavirus infections and a high doubling rate, orange zones have fewer cases than red zones, and green zones had no cases in the previous 21 days.

Methods and materials

Instrument/Products/Software

The most recent version of the Multi-angle Implementation of Atmospheric Correction (MAIAC) algorithm have been used to derive aerosol data from MCD19A2 V6 gridded L2 AOD_{MAIAC} at 550 nm. The combined MODIS Terra and Aqua products daily at 1 km resolution have been obtained through https://ladsweb.modaps.eosdis.nasa.gov/. Data from the AOD_{MAIAC} have been processed using MATLAB for the years 2019, 2020, and 2021, and the percent change between the years has been mapped using Origin2022b.

Derivation of AOD from MODIS MAIAC Aerosol Product

MCD19A2 V6 gridded L2 AOD_{MAIAC} at 550 nm, obtained daily at 1 km resolution, has been used as the aerosol data. The combined MODIS Terra and

Aqua product have been obtained using the most current version of the Multi-angle Implementation of Atmospheric Correction (MAIAC) algorithm (Lyapustin, Wang, Korkin, & Huang, 2018). Such Terra and Aqua MAIAC product (MCD19A2; https://ladsweb.modaps.eosdis.nasa.gov/) have been used to derive AOD$_{MAIAC}$ data at 550nm with Scientific Data Set (SDS) "Aerosol Optical Depth at 550nm" for the year 2019, 2020, and 2021 in the current study. The cloud mask value "clear" for Quality Assurance (QA) indicates that the data is of the highest quality. The AOD$_{MAIAC}$ data has been downloaded through https://ladsweb.modaps.eosdis.nasa.gov/ and processed for 2019, 2020, and 2021 using MATLAB software. During pre-processing, a specific Scientific Data Set (SDS) was extracted, as well as masking of the current study region. AOD$_{MAIAC}$ has been analyzed for air quality assessment in various phases of COVID-19's lockdown (pre-lockdown, during first & second lockdown) (Table 1). The change in aerosol concentrations between PL and FL, SL and FL has been calculated using Equation 1 and Equation 2:

$$\left(\frac{(FL\ concentration - PL\ concentration)}{(PL\ concentration)}\right) * 100 \qquad (1)$$

$$\left(\frac{(SL\ concentration - FL\ concentration)}{(FL\ concentration)}\right) * 100 \qquad (2)$$

The daily AOD$_{MAIAC}$ data has been divided into phases of lockdown for three years, and spatial distribution of AOD has been represented in Figures 2-5. Mean AOD has been calculated by averaging the phased data for a particular year.

Time Frame of the Analysis

To explore the variation of AOD with lockdown explicitly, the analysis period has been divided into three sub-periods and 4 phases of lockdown. Phase 1(P – I) includes: (March 25 to April 14, 2019-Winter to Pre-monsoon) pre-lockdown (PL), (March 25 to April 14, 2020- Pre-monsoon) during first lockdown (FL), (March 25 to April 14, 2021-Pre-monsoon) during the second lockdown). Subsequently, spatial distribution of AOD has been compared from PL to FL to SL during Phase-I, keeping the season constant (Winter to Pre-monsoon). Likewise, AOD has been compared for other phases (Phase 2, Phase 3, Phase 4) (Table 1).

Table 1: Various phases of lockdown [Pre-lockdown (PL), first lockdown (FL) & second lockdown (SL)]

Duration	Details			Activities
P-I	25 March – 14 April	PL	2019	Normal activities
		FL	2020	Non-essential activities (gym, malls, entertainment, cultural etc.) came to halt
		SL	2021	Partial activities allowed (schools, offices remained shut)
P-II	15 April – 3 May	PL	2019	Normal activities
		FL	2020	Previous lockdown has been maintained, and important modifications in policies have been framed as preparation for further lockdown.
		SL	2021	Partial activities allowed (schools, offices remained shut)
P-III	4 May – 17 May	PL	2019	Normal activities
		FL	2020	Region's categorization based on the pandemic and relaxation in restrictions in the red, green, and orange zone
		SL	2021	Partial activities allowed (schools, offices remained shut)
P-IV	18 May – 31 May	PL	2019	Normal activities
		FL	2020	Further relaxation in red zone area where the COVID-19 cases are relatively high
		SL	2021	Partial activities allowed (schools, offices remained shut)

Results and Discussions

The AOD$_{MAIAC}$ has been pre-processed using MATLAB R2019b software for 2019, 2020, and 2021. After the pre-processing, AOD$_{MAIAC}$ has been divided into AOD$_{MAIAC}$ PL, AOD$_{MAIAC}$ FL, and AOD$_{MAIAC}$ SL as discussed in the methodology section. The mean value of AOD$_{MAIAC}$ for these durations has been considered for the study. The highest AOD has been observed during P-III of SL. A drop in AOD has been noted in the P-I of FL. Overall, a change of 5% to 36% has been observed in different phases.

During complete lockdown period in 2020, the aerosol concentration decreased in the current study area compared to PL period in 2019. Similar observations have been reported for Delhi and other parts of northern India by earlier research (Garg, Kumar, & Gupta, 2021; Pathakoti et al., 2021; Pramod, 2021). In 2021, unlike in other parts of India, the present study area was still under partial lockdown. However, contrary to the general expectations, aerosol concentration increased compared to the FL and PL situations even. Such findings indicate the impact of anthropogenic activities on air pollution which calls for strict policies and its proper implementation to control pollution levels. During this partial lockdown, production in industries gets doubled to meet the increasing demand, which could be one of the probable reasons for abrupt increase in AOD. The other possible reason could be the vehicular emission resulted from cross-border checking which led to rise in AOD concentration. Moreover, drastic increase in AOD over the study area could be attributed to the increased incidents of field-fires for stubble-burning after wheat harvest in Punjab, Haryana and Western Uttar Pradesh (Shahnawaz, 2021). Besides such anthropogenic factor, atmospheric moisture, intricate chemical reactions, surface and upper-air circulation, wind speed could be the driving climatic factors responsible for AOD increase (Pandey & Vinoj, 2021; Pramod, 2021).

Spatial distribution of AOD_{MAIAC} have been depicted phase-wise for 2019, 2020, and 2021during three situations (PL, FL, and SL) in Figures 2-5 to analyse the pattern of AOD anomaly during pre-lockdown and during complete and partial lockdown. The highest AOD recorded were 0.68 (PL), 0.7 (FL) and 0.9 (SL). During P-I, all the four districts in the study area maintain low AOD (0.2-0.5) during FL and SL and even PL. AOD are divided in to four categories a) Low (0-0.2) b) Moderate (0.2-0.5), c) High (0.5-0.8) and d) Very High (0.8-1). During P-I, PL, Ghaziabad and Gurugram were in moderate and low category respectively. During FL AOD decreased compared to the pre-lockdown period. On the contrary, aerosol concentration increased in Gurugram, Faridabad, and Gautam Buddha Nagar.

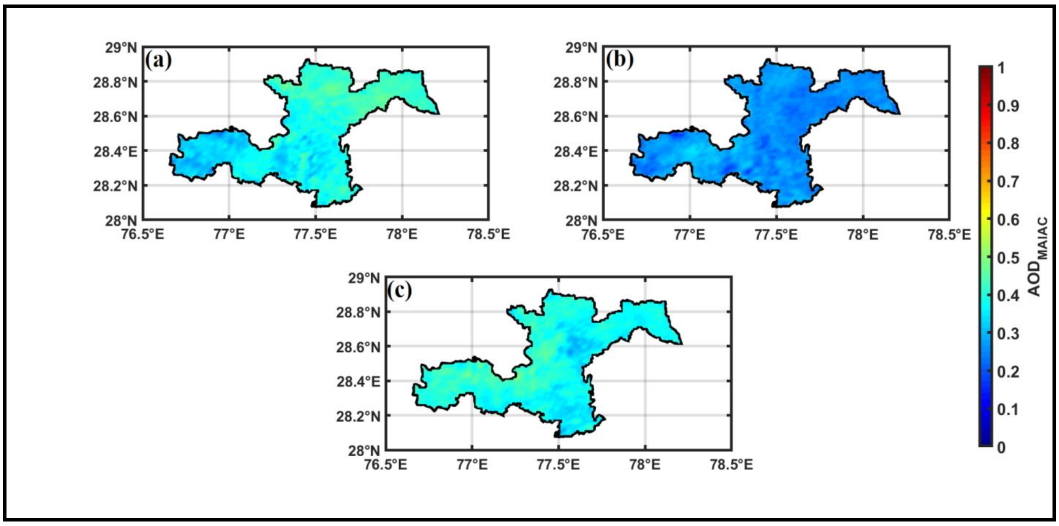


Fig. 2: Spatial distribution of AOD_{MAIAC} during first phase (P-I) a) PL b) FL and c) SL

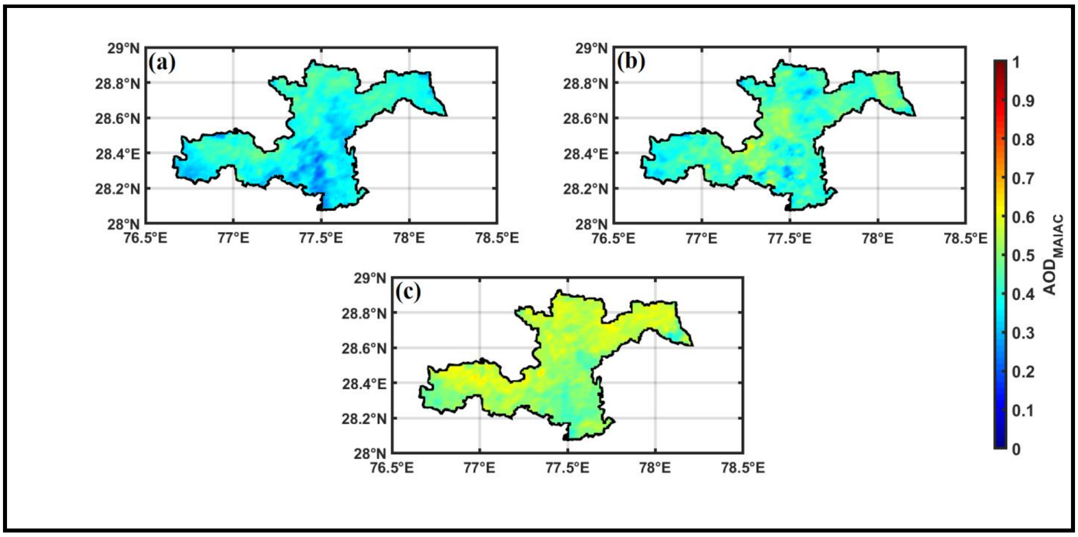


Fig. 3: Spatial distribution of AOD_{MAIAC} during second phase (P-II) a) PL b) FL and c) SL

During P-II, Gurugram and Ghaziabad were in moderate category with respect to AOD, while parts of Faridabad and Gautam Buddha Nagar were in low category in pre-lockdown period unlike P-I. The aerosol concentration has increased during the FL, bringing several portions of Faridabad, Ghaziabad, Gurugram, and Gautam Buddha Nagar into the moderate class, which were in low category during P-I. Various anthropogenic activities were typically exempted during P-II lockdown, resulting in an increase in aerosol concentrations during FL. In addition, aerosol concentration during SL has increased over time and the study area now falls into the high category.

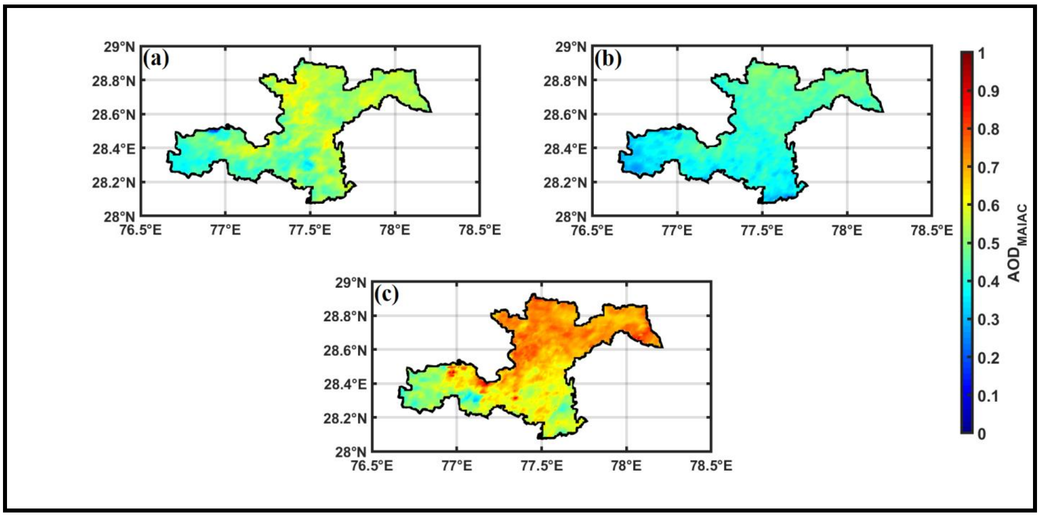


Fig. 4: Spatial distribution of AOD$_{MAIAC}$ during third phase (P-III) a) PL b) FL and c) SL

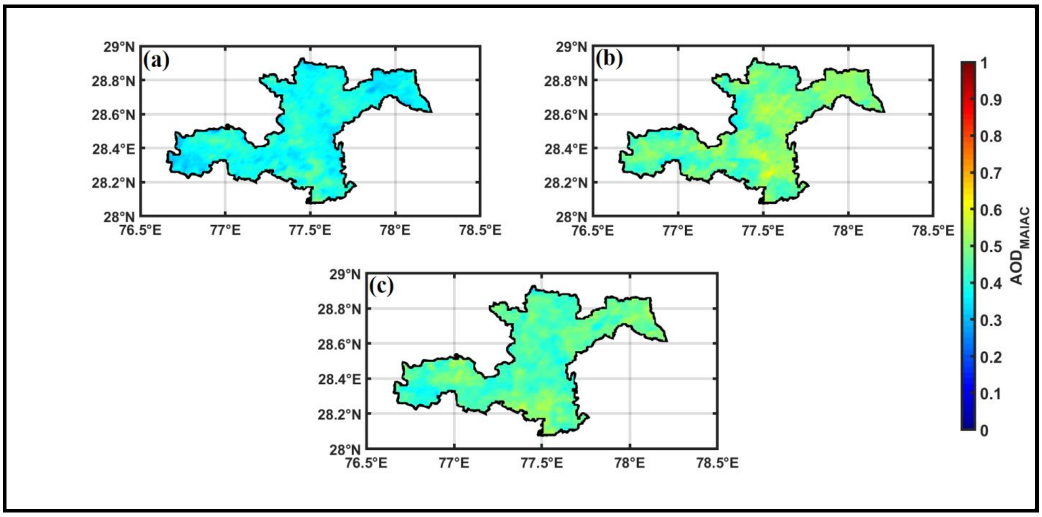


Fig. 5: Spatial distribution of AOD$_{MAIAC}$ during P-IV of a) PL b) FL and c) SL

Compared to P-I and II, an increase in aerosol concentrations have been observed in P-III during pre-lockdown and SL period. However, during FL, aerosol concentration was low due to the reintroduction of restrictions following an increase in COVID-19 cases. High to very high concentration zones have been identified mostly in Gautam Budh Nagar and Ghaziabad.

In P-IV, the aerosol concentration remained moderate during pre-lockdown period, as opposed to P-I and P-II, which had low concentration zones in some areas. Compared to all the preceding phases, the aerosol concentrations during FL increased from moderate to high in P-IV due to relaxation of restrictions as unlocking commenced and then remain moderate during the SL period.

Figure 6 (a) shows the average AODMAIAC for the three periods: Pre- lockdown, during FL, and SL. The percent change in AODMAIAC over time in various phases can be depicted through Figure 6 (b). The lowest and highest AOD has been observed during P-I, FL (0.26) and P-III, SL (0.64) respectively. Prior to the lockdown, prime sources of aerosol in the current study area are emissions from factories, vehicles, and construction projects. The average AOD in pre-lockdown period was 0.3. During the phase one of initial lockdown (P-I, FL), all operations came to a standstill, including emissions from industries, automobiles, and construction resulting into a decrease of aerosol concentration (AOD ~ 0.26). Few necessary activities were allowed to take place during P-II. Therefore, the aerosol concentrations started rising in the Phase-II of FL. In the third phase (P-III), the entire lockdown was imposed yet again, resulting in a drop in AOD. In the fourth phase (P-IV), the partial lockdown persisted, although there was some relaxation in few areas, contributing to the rise in aerosol concentration and the highest AODMAIAC. Further, during FL, reduction in AOD was observed in the 1st and 3rd phases contrary to 2nd and 4th phases. AOD was higher during SL compared to FL. In 2021, when the second wave of COVID-19 hit the world, the current study area was subjected to a second partial lockdown resulted the fluctuations in AOD.

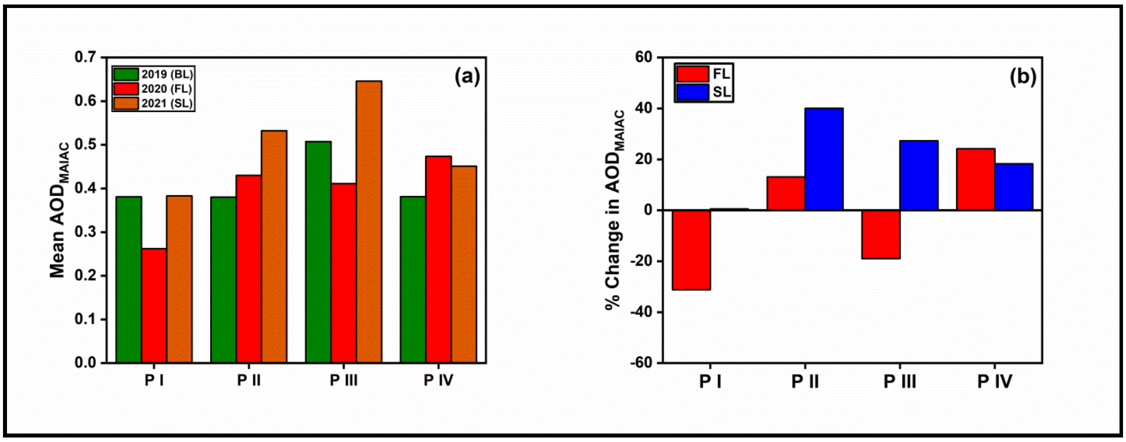


Fig. 6: Representation of (a) Mean AODMAIAC and (b) percent change of AOD during FL, and SL from pre-lockdown period in PI-IV

Percentage change in in pre-lockdown and during first & second lockdown has been depicted in Figures 6(b), 7, 8. Observed change during SL is positive, indicating that the AOD has been increased during SL compared to FL. The P-II and P-IV has shown a positive percentage change. was attributed to meteorological activities and anthropogenic activities. P-I (-31.19 %) and P-III (-19.01 %), observed a negative change, exhibiting decrease in AOD compared pre-lockdown period due to the complete lockdown and thereby stoppage of the prominent sources of emissions. The anthropogenic and meteorological factors both contributed to the positive shift in P-II (13.11%) and P-IV (24.22%). During the second phase, the most considerable increase was noted in Faridabad and sections of Gautam Buddha Nagar, while the P-IV, substantial increase in AOD occurred throughout the study area (Fig. 7).

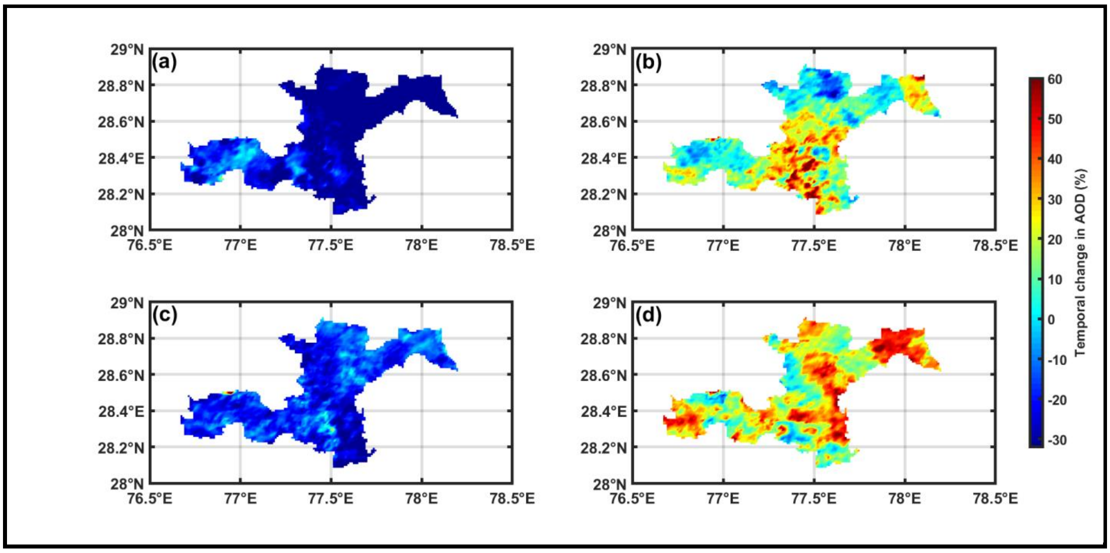


Fig. 7: Phase-wise AODMAIAC anomaly- FL-PL (2020-2019) (a) P-I (b) P-II (c) P-III and (d) P-IV

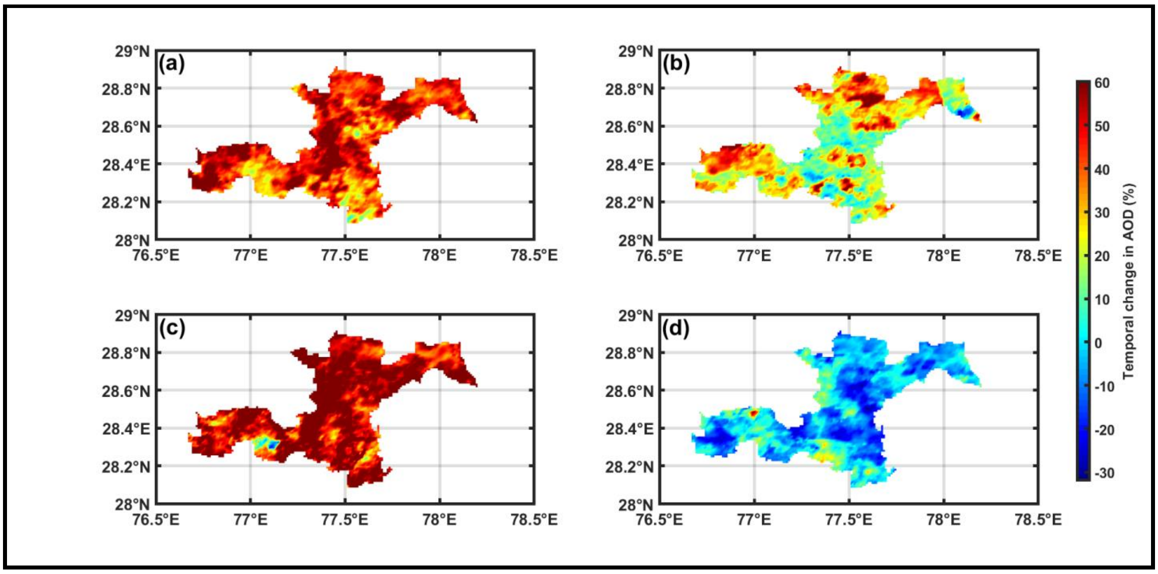


Fig. 8: Phase-wise AODMAIAC anomaly map of SL-FL (2021-2020) (a) P-I (b) P-II (c) P-III and (d) P-IV

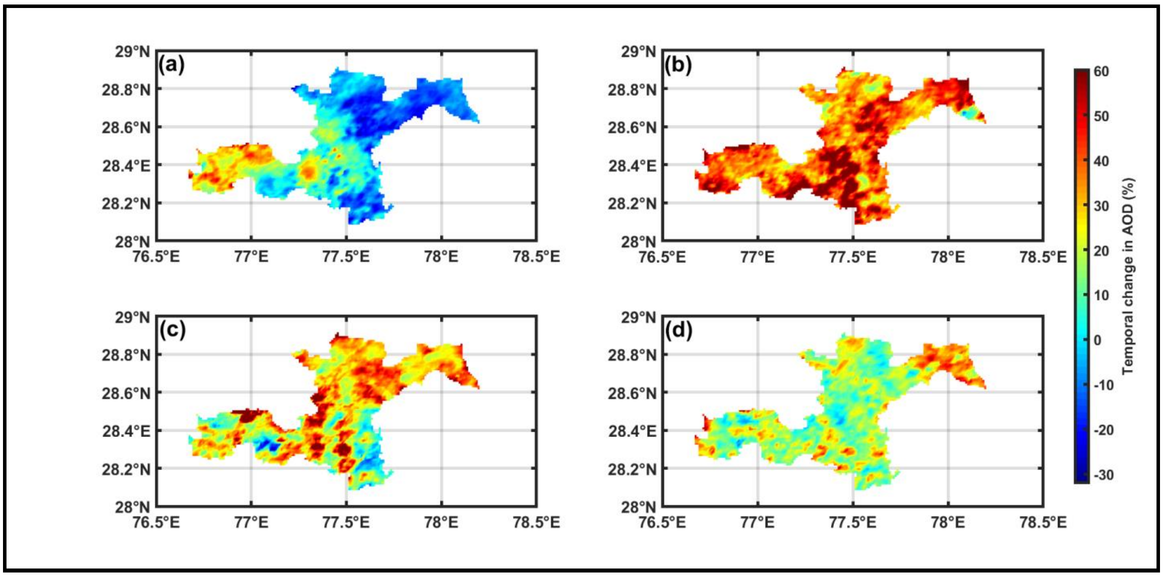


Fig. 9: Phase-wise AODMAIAC anomaly map of SL-PL (2021-2019) (a) P-I (b) P-II (c) P-III and (d) P-IV

During the SL in first three phases [P-I (46.13 %), II (23.81%), III (57.22 %), and IV (-4.79 %)] the AOD has been increased due to anthropogenic and meteorological activities (Fig. 8). A positive change has been observed during the SL in all the phases [P-I (0.55 %), II (40.03%), III (27.32 %), and IV (18.24 %)] compared to pre-lockdown period (Fig. 9). The highest positive change has been seen in the P-II and the P-III during the second lockdown (Fig. 8).

Various research published earlier reported a reduction in pollution levels in entire north India and the metropolitan cities (Delhi, Kolkata, Mumbai) during the first lockdown compared to pre-lockdown period from 2019 to 2020 and lowest AOD has been measured in April 2020 (Ahamed Ibrahim S.N., Sri Shalini S, Ramachandran A, & Palanivelu K, 2022a; Chinmay et al., 2021; Fatima, Ahlawat, Mishra, Maheshwari, & Soni, 2022; Pramod, 2021; Shahnawaz, 2020; Sudesh, Sushil, Rimpi, & Sudesh, 2021) . Ambient concentration levels in the Gangetic plain remained close to the 24-hour standard limit while in the south, AODMAIAC levels increased, demonstrating the susceptibility to climate factors (Ahamed Ibrahim S.N., Sri Shalini S, Ramachandran A, & Palanivelu K, 2022b; A. K. Ranjan, Patra, & Gorai, 2020). Present study mainly focused on analyzing the AOD pattern during the first and second lockdown periods (2020-2021) and compared it with pre-lockdown aerosol concentration in 2019. Our study first reported a significant increase in AOD levels during the second lockdown period compared to the previous times. Contrary to the previous research carried on a regional scale, our micro-level study remarked that COVID-19 pandemic-induced lockdown events significantly improved air quality in India's most polluted cities in some phases, while shocking increase in AOD has been observed in few phases especially during SL due to the leniency of the lock down and transmission of aerosol particles by pre-monsoonal winds. Severely polluted regions throughout the previous decade (Sikarwar & Rani, 2020), had a significant drop in aerosol levels only in the first and third phase of FL. Variations in aerosol concentrations have been detected across all phases due to the intricacies of meteorological and anthropogenic factors.

Conclusion

The COVID-19 pandemic becomes a serious hazard to human health and a significant economic loss over the world. While the pandemic-induced lockdown indicates that nature can heal itself if humans give it a chance, the present research emphasized that pandemic-induced lockdown significantly reduced AOD levels across the top polluted regions. During phase-wise lockdowns in the satellite cities of Delhi, the spatial and temporal variations of AOD have been investigated. From March 25, 2020, to May 14, 2020, the differences in aerosol concentration levels during lockdowns have been examined using AOD_{MAIAC}. AOD_{MAIAC} was lower by around 20% to 90% during lockdown stages. The concentration of aerosol decreased dramatically due to several rigorous measures adopted during the lockdown limiting public and private transportation and halting industrial and commercial activity and thereby significant decreasing local pollutants from vehicle exhaust and industrial activities. Interestingly, during the first phase, the AOD_{MAIAC} levels decreased, however, in the second phase, AOD level increased as the relaxation in restrictions were sanctioned. During the second and fourth phase of FL, the AOD levels were high in comparison to pre-lockdown period. During SL, AOD were higher compared to FL and PL for the current study area in all the four phases which clearly illustrates that proper rule, norms, and standards can keep the ambient air quality in check. Besides the regional scale, our micro-level analysis illustrates the conditions at the local scale and signifies that the chemistry of pollutants in the environment, emission sources, and meteorological conditions together influence the number of pollutants in ambient air. Since the results indicate that vehicles, industry, and construction activities are the primary causes of air pollution in Delhi NCR, severe pollution-reduction measures, as well as regulations and norms tailored to the current circumstances are necessary.

Acknowledgements

The corresponding author acknowledges the Science & Engineering Research Board (SERB), Department of Science & Technology (DST), Government of India for funding this work through Project File No. ECR/2017/000331. Present research is partially supported for mobility activity by the ERASMUS+ Programme of the European Union.

Funding

This research was funded by Science & Engineering Research Board (SERB), Department of Science & Technology (DST), Government of India (Project File No. ECR/2017/000331). It is also partially supported for mobility activity by the ERASMUS+ Programme of the European Union.

Acknowledgements

MODIS AOD products were available at Level-1 Atmosphere Archive & Distribution System (LAADS) (https://ladsweb.modaps.eosdis.nasa.gov/). Authors are thankful to NASA AERONET federation, AERONET scientific team and principal investigators for establishing, maintaining the sites, and providing AERONET data at https://aeronet.gsfc. nasa. gov/.

Author contribution

Conceptualization, S.G; methodology, X.X.; formal analysis, V.S.; investigation, V.S.; S.G. writing—original draft preparation, V.S.; writing—review and editing, S.G.; S; P.K.R.; Resources provision: S.; P.K.R.; S.S. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Ahamed Ibrahim, S.N., Sri Shalini, S., Ramachandran, A., & Palanivelu, K. (2022a). Spatio-temporal variation and sensitivity analysis of aerosol particulate matter during the COVID-19 phase-wise lockdowns in Indian cities. *Journal of Atmospheric Chemistry*, 79(1), 39–66. https://doi.org/10.1007/s10874-021-09428-7

Ahamed Ibrahim, S.N., Sri Shalini, S., Ramachandran, A., & Palanivelu K. (2022b). Spatio-temporal variation and sensitivity analysis of aerosol particulate matter during the COVID-19 phase-wise lockdowns in Indian cities. *Journal of*

Atmospheric Chemistry. https://doi.org/10.1007/s10874-021-09428-7

Baldasano, J. M. (2020). COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain). *Science of The Total Environment*, 741, 140353. https://doi.org/10.1016/J.SCITOTENV.2020.140353

Bedi, J. S., Dhaka, P., Vijay, D., Aulakh, R. S., & Gill, J. P. S. (2020). Assessment of air quality changes in the four metropolitan cities of india during COVID-19 pandemic lockdown. *Aerosol and Air Quality Research*, 20(10), 2062–2070. https://doi.org/10.4209/aaqr.2020.05.0209

Chauhan, A., & Singh, R. P. (2020). Decline in PM 2 . 5 concentrations over major cities around the world associated with COVID-19, (January).

Chen, Q. X., Huang, C. L., Yuan, Y., & Tan, H. P. (2020). Influence of covid-19 event on air quality and their association in mainland China. *Aerosol and Air Quality Research*, 20(7), 1541–1551. https://doi.org/10.4209/aaqr.2020.05.0224

Chinmay, M., Harish, G., Shyam, L., Rahul, Y. K., R., B., & Trupti, D. (2021). fenvs-2021-743894 1..20 _ Enhanced Reader.pdf. *Frontiers in Environmental Science*. https://doi.org/10.3389/fenvs.2021.743894

Council, I., & Medical, O. F. (2017). *Indian Council for Medical Research: National Ethical Guidelines for Biomedical and Health Research Involving Human Participants, 2017. Indian Council for Medical Research*.

Dantas, G., Siciliano, B., França, B. B., da Silva, C. M., & Arbilla, G. (2020). The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Science of the Total Environment*, 729, 139085. https://doi.org/10.1016/j.scitotenv.2020.139085

Fadnavis, S., Semeniuk, K., Pozzoli, L., Schultz, M. G., Ghude, S. D., Das, S., & Kakatkar, R. (2013). Transport of aerosols into the UTLS and their impact on the asian monsoon region as seen in a global model simulation. *Atmospheric Chemistry and Physics*, 13(17), 8771–8786. https://doi.org/10.5194/acp-13-8771-2013

Fadnavis, Suvarna, Sabin, T. P., Rap, A., Müller, R., Kubin, A., & Heinold, B. (2021). The impact of COVID-19 lockdown measures on the Indian summer monsoon. *Environmental Research Letters*, 16(7). https://doi.org/10.1088/1748-9326/ac109c

Fatima, S., Ahlawat, A., Mishra, S. K., Maheshwari, M., & Soni, V. K. (2022). Variations and Source Apportionment of PM2.5 and PM10 Before and During COVID-19 Lockdown Phases in Delhi, India. Mapan - *Journal of Metrology Society of India*. https://doi.org/10.1007/s12647-021-00506-5

Garg, A., & Gupta, N. C. (2019). A comprehensive study on spatio-temporal distribution, health risk assessment and ozone formation potential of BTEX emissions in ambient air of Delhi, India. *Science of The Total Environment*, 659, 1090–1099. https://doi.org/10.1016/J.SCITOTENV.2018.12.426

Garg, A., Kumar, A., & Gupta, N. C. (2021). Comprehensive study on impact assessment of lockdown on overall ambient air quality amid COVID-19 in Delhi and its NCR, India. *Journal of Hazardous Materials Letters*, 2(October 2020), 100010. doi.org/10.1016/j.hazl.2020.100010

Gautam, A. S., Dilwaliya, N. K., Srivastava, A., Kumar, S., Bauddh, K., Siingh, D., … Gautam, S. (2021). Temporary reduction in air pollution due to anthropogenic activity switch-off during COVID-19 lockdown in northern parts of India. *Environment, Development and Sustainability*, 23(6), 8774–8797. https://doi.org/10.1007/s10668-020-00994-6

Gautam, S. (2020). The Influence of COVID-19 on Air Quality in India: A Boon or Inutile. Bulletin of *Environmental Contamination and Toxicology*, 104(6), 724–726. https://doi.org/10.1007/S00128-020-02877-Y

Ghosh, S., N., K. V., Kumar, S., & Midya, K. (2021). Seasonal Contrast of Land Surface Temperature in Faridabad: An Urbanized District of Haryana, India. In *Methods and Applications of Geospatial Technology in Sustainable Urbanism* (pp. 217–250). IGI Global. https://doi.org/10.4018/978-1-7998-2249-3.ch008

Government of India. (2020). *Ministry of India, Guidelines*. Government of India (Vol. 25). Retrieved from http://dx.doi.org/10.1016/j.jss.2014.12.010%0Ahttp://dx.doi.org/10.1016/j.sbspro.2013.03.034%0Ahttps://www.iiste.org/Journals/index.php/JPID/article/viewFile/19288/19711%0Ahttp://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.678.6911&rep=rep1&type=pdf

Gulia, S., Nagendra, S. M. S., & Khare, M. (2017). A system based approach to develop hybrid model predicting extreme urban NOx and PM2.5 concentrations. *Transportation Research Part D: Transport and Environment*, 56(220), 141–154. https://doi.org/10.1016/j.trd.2017.08.005

Guttikunda, S. K., Goel, R., & Pant, P. (2014). Nature of air pollution, emission sources, and management in the Indian cities. *Atmospheric Environment*, 95, 501–510. https://doi.org/10.1016/j.atmosenv.2014.07.006

Hama, S. M. L., Kumar, P., Harrison, R. M., Bloss, W. J., Khare, M., Mishra, S., … Sharma, C. (2020). Four-year assessment of ambient particulate matter and trace gases in the Delhi-NCR region of

India. *Sustainable Cities and Society*. https://doi.org/10.1016/j.scs.2019.102003

IHME. (2019). *A SPECIAL REPORT ON GLOBAL EXPOSURE TO AIR POLLUTION AND ITS DISEASE BURDEN What is the State of Global Air? Who is it for? How can I explore the data? Boston, MA:Health Effects Institute*. Retrieved from http://www.stateofglobalair.org/sites/default/files /soga_2019_report.pdf

Jain, M., Taubenböck, H., & Namperumal, S. (2011). Seamless urbanisation and knotted city growth: Delhi Metropolitan Region. *Real Corp* 2011, (May), 1–10. https://doi.org/10.3188/szf.2006.0499

Jain, S., & Sharma, T. (2020). Social and travel lockdown impact considering coronavirus disease (Covid-19) on air quality in megacities of india: Present benefits, future challenges and way forward. *Aerosol and Air Quality Research*, 20(6), 1222–1236. https://doi.org/10.4209/aaqr.2020.04.0171

Jiang, Z., Shi, H., Zhao, B., Gu, Y., Zhu, Y., Miyazaki, K., … Liou, K. N. (2021). Modeling the impact of COVID-19 on air quality in southern California: Implications for future control policies. *Atmospheric Chemistry and Physics*, 21(11), 8693–8708. https://doi.org/10.5194/acp-21-8693-2021

Kumar, S., Ghosh, S., Hooda, R. S., & Singh, S. (2019). Monitoring and prediction of land use land cover changes and its impact on land surface temperature in the central part of hisar district, Haryana under semi-arid zone of India. *Journal of Landscape Ecology (Czech Republic)*, 12(3), 117–140. https://doi.org/10.2478/jlecol-2019-0020

Kumar, S., Ghosh, S., & Singh, S. (2022). Polycentric urban growth and identification of urban hot spots in Faridabad, the million-plus metropolitan city of Haryana, India: a zonal assessment using spatial metrics and GIS. *Environment, Development and Sustainability*, 24(6), 8246–8286. https://doi.org/10.1007/s10668-021-01782-6

Kumar, S., Midya, K., Ghosh, S., & Singh, S. (2021). Pixel-Based vs. Object-Based Anthropogenic Impervious Surface Detection: Driver for Urban-Rural Thermal Disparity in Faridabad, Haryana, India. *Geocarto International*, 0(0), 1–23. https://doi.org/10.1080/10106049.2021.2002429

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J. P., Abernethy, S., Andrew, R. M., … Peters, G. P. (2020). Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, 10(7), 647–653. https://doi.org/10.1038/s41558-020-0797-x

Li, L., Li, Q., Huang, L., Wang, Q., Zhu, A., Xu, J., … Chan, A. (2020). Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. *Science of the Total Environment*, 732. https://doi.org/10.1016/j.scitotenv.2020.139282

Lolli, S., & Vivone, G. (2020). The role of tropospheric ozone in flagging COVID-19 pandemic transmission. *Bulletin of Atmospheric Science and Technology*, 1(3–4), 551–555. https://doi.org/10.1007/s42865-020-00026-1

Lyapustin, A., Wang, Y., Korkin, S., & Huang, D. (2018). MODIS Collection 6 MAIAC algorithm. *Atmospheric Measurement Techniques*, 11(10), 5741–5765. https://doi.org/10.5194/amt-11-5741-2018

Mishra, M. K., & Rathore, P. S. (2021). Impact of nationwide covid-19 lockdown on indian air quality in terms of aerosols as observed from the space. *Aerosol and Air Quality Research*, 21(4). https://doi.org/10.4209/aaqr.2020.07.0461

Muhammad, S., Long, X., & Salman, M. (2020). COVID-19 pandemic and environmental pollution: A blessing in disguise? *Science of the Total Environment*, 728. https://doi.org/10.1016/J.SCITOTENV.2020.138820

Paital, B. (2020). Nurture to nature via COVID-19, a self-regenerating environmental strategy of environment in global context. *The Science of the Total Environment*, 729, 139088. https://doi.org/10.1016/j.scitotenv.2020.139088

Pandey, S. K., & Vinoj, V. (2021). Surprising changes in aerosol loading over india amid covid-19 lockdown. *Aerosol and Air Quality Research*, 21(3), 1–12. https://doi.org/10.4209/aaqr.2020.07.0466

Pathakoti, M., Muppalla, A., Hazra, S., Venkata, M. D., Lakshmi, K. A., Sagar, V. K., … Vijayasundaram, U. (2021). Measurement report: An assessment of the impact of a nationwide lockdown on air pollution - A remote sensing perspective over India. *Atmospheric Chemistry and Physics*, 21(11), 9047–9064. https://doi.org/10.5194/acp-21-9047-2021

Pramod, S. (2021). Effects of COVID-19 lockdown phases in India:an atmospheric perspective. *Environment, Development and Sustainability*, 23, 12044–12055. https://doi.org/https://doi.org/10.1007/s10668-020-01156-4

Rani, S., & Kumar, R. (2022). Spatial distribution of aerosol optical depth over India during COVID-19 lockdown phase-1. *Spatial Information Research*. https://doi.org/10.1007/s41324-022-00442-9

Ranjan, A. K., Patra, A. K., & Gorai, A. K. (2020). Effect of lockdown due to SARS COVID-19 on aerosol optical depth (AOD) over urban and mining regions in India. *Science of the Total Environment*, 745, 141024. https://doi.org/10.1016/j.scitotenv.2020.141024

Ranjan, K., Sharma, V., & Ghosh, S. (2022). Assessment of Urban Growth and Variation of Aerosol Optical Depth in Faridabad District, Haryana, India, 8(2), 447–461. https://doi.org/10.22059/POLL.2021.329185.1163

Sanap, S. D. (2021). Global and regional variations in aerosol loading during COVID-19 imposed lockdown. *Atmospheric Environment*, 246(December 2020), 118132. https://doi.org/10.1016/j.atmosenv.2020.118132

Shahnawaz, S. (2020). Mean Monthly Aerosol Optical Thickness (AOT) in April Month from 2001 to 2020 INDEX :, (May). https://doi.org/10.13140/RG.2.2.26800.17921

Shahnawaz, S. (2021). Monitoring the 'Grey-Effect' of Green Revolution Region in India. Background of the Study, (December). https://doi.org/10.13140/RG.2.2.33628.92805

Sharma, S. K., Mandal, T. K., Rohtash, Kumar, M., Gupta, N. C., Pathak, H., … Saxena, M. (2014). Measurement of Ambient Ammonia over the National Capital Region of Delhi, India. Mapan - *Journal of Metrology Society of India*, 29(3), 165–173. https://doi.org/10.1007/s12647-014-0098-9

Sharma, S., Zhang, M., Anshika, Gao, J., Zhang, H., & Kota, S. H. (2020). Effect of restricted emissions during COVID-19 on air quality in India. *Science of the Total Environment*, 728, 138878 https://doi.org/10.1016/j.scitotenv.2020.138878

Sharma, V., Ghosh, S., Bilal, M., Dey, S., & Singh, S. (2021). Performance of MODIS C6.1 Dark Target and Deep Blue aerosol products in Delhi National Capital Region, India: Application for aerosol studies. *Atmospheric Pollution Research*, 12(3), 65–74. https://doi.org/10.1016/j.apr.2021.01.023

Sharma, V., Ghosh, S., Kumari, M., Taloor, A. K., Singh, S., Arola, A., & Devara, P. C. S. (2022). Analysis and Variation of the Maiac Aerosol Optical Depth in Underexplored Urbanized Area of National Capital Region, India. *Journal of Landscape Ecology (Czech Republic)*, 15(3), 82–101. https://doi.org/10.2478/jlecol-2022-0019

Sharma, V., Ghosh, S., Singh, S., Vishwakarma, D. K., Al-Ansari, N., Tiwari, R. K., & Kuriqi, A. (2022). Spatial Variation and Relation of Aerosol Optical Depth with LULC and Spectral Indices. Atmosphere, (13), 1992. https://doi.org/https://doi.org/10.3390/atmos13121992

Shukla, N., Sharma, G. K., Baruah, P., Shukla, V. K., & Gargava, P. (2020). Impact of Shutdown due to COVID-19 Pandemic on Aerosol Characteristics in Kanpur, India. *Journal of Health and Pollution*, 10(28), 1–12. https://doi.org/10.5696/2156-9614-10.28.201201

Sikarwar, A., & Rani, R. (2020). Assessing the Immediate Effect of Covid-19 Lockdown on Air Quality: A Case Study of Delhi, India. *Journal of Environmental Geography*, 13(3–4), 27–33 https://doi.org/10.2478/jengeo-2020-0009

Simone, L., Ying-Chieh, C., Sheng-Hsiang, W., & Gemine, V. (2020). Impact of meteorological conditions and air pollution on COVID-19 pandemic transmission in Italy, 10, 16213. https://doi.org/https://doi.org/10.1038/s41598-020-73197-8

Singh, S., & Peshin, S. K. (2014). Air Pollution Scenario over Delhi City. In M. H. Fulekar, B. Pathak, & R. K. Kale (Eds.), *Environment and Sustainable Development* (pp. 77–85). New Delhi: Springer India. https://doi.org/10.1007/978-81-322-1166-2_6

Singh, T., Ravindra, K., Sreekanth, V., Gupta, P., Sembhi, H., Tripathi, S. N., & Mor, S. (2020). Climatological trends in satellite-derived aerosol optical depth over North India and its relationship with crop residue burning: Rural-urban contrast. *Science of the Total Environment*, 748, 140963. https://doi.org/10.1016/j.scitotenv.2020.140963

Sudesh, C., Sushil, K., Rimpi, A., & Sudesh, Y. (2021). new delhi.pdf. *Journal of Health and Pollution*

Thomas, A., Sarangi, C., & Kanawade, V. P. (2019). Recent Increase in Winter Hazy Days over Central India and the Arabian Sea. *Scientific Reports*, 9(1), 1–10. https://doi.org/10.1038/s41598-019-53630-3

Tobías, A., Carnerero, C., Reche, C., Massagué, J., Via, M., Minguillón, M. C., … Querol, X. (2020). Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Science of the Total Environment*, 726, 138540. https://doi.org/10.1016/j.scitotenv.2020.138540

WAQR. (2019). *World Air Quality Report, IQAir*

WHO (2020b). (2020). *Coronavirus disease (COVID-19) Situation Report 107. Coronavirus Disease*

World Air Quality Report 2020, Iqa. (2020). *World Air Quality Report, IQAir*

Xu, K., Cui, K., Young, L. H., Wang, Y. F., Hsieh, Y. K., Wan, S., & Zhang, J. (2020). Air quality index, indicatory air pollutants and impact of covid-19 event on the air quality near central china. *Aerosol and Air Quality Research*, 20(6), 1204–1221. https://doi.org/10.4209/aaqr.2020.04.0139

Yunus, A. P., Masago, Y., & Hijioka, Y. (2020). COVID-19 and surface water quality : Improved lake water quality during the lockdown, (January)

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **158**-**171**
http://dx.doi.org/**10.5775/fg.2022.039.d**

Solid waste management as an urban area regulation in Algeria. Case of El-Khroub city

Naziha LAMRI[1], Amna BELAYADI[2], Faiza ABBAS[1,*]

[1] Laboratory for the Management and Valorisation of Natural Resources and Quality Assurance, Akli Mohand Oulhadj University of Bouira, Algeria
[2] University of frères Mentouri Constantine 1, Faculty of Earth Sciences, Department of Geography and Land Use Planning, Constantine, Algeria
[3] University of Science and Technology Houari Boumediene (USTHB), Faculty of Earth Sciences, Department of Geography and Land Use Planning, Algiers, Algeria
* *Corresponding author*: n.lamri@univ-bouira.dz

Received on 20-07-2022, reviewed on 23-11-2022, accepted on 07-12-2022

Abstract

The phenomenon of urban pollution is one of the most serious problems that affect people in the world, as it causes the spread of epidemics and diseases that threaten their health. As in the case of other societies, this also represents an important issue for Algeria. Therefore, through this work, we decided to take an example of urban pollution in an Algerian city of historical and administrative importance, represented by the city of El-Khroub located in the province of Constantine; the aim was to monitor the reality of urban waste management in the city center, the disinfection and disposal of urban solid waste. Through this, we monitored the most important ways that local authorities follow to eliminate solid waste, including landfill or incineration, where household waste annually reaches 2045328 tons. The dirt still floats in the city neighborhoods, because of the ignorance of the population, as well as the lack of authorities to ensure a clean and sustainable environment.

Keywords: *pollution, waste management, El-Khroub city, urban solid waste, inert waste, Algeria*

Rezumat. Managementul deșeurilor solide ca reglementare urbană în Algeria. Cazul orașului El-Khroub

Poluarea urbană este una dintre cele mai serioase probleme care afectează oamenii din întreaga lume, contribuind la răspândirea epidemiilor și a bolilor ce reprezintă o amenințare la adresa sănătății tuturor. Ca și în cazul altor societăți, deșeurile sunt o problemă și pentru Algeria. Prin urmare, în cadrul acestei lucrări ne-am propus să luăm ca exemplu poluarea urbană dintr-un oraș algerian important din punct de vedere istoric și administrativ, respectiv orașul El-Khroub, localizat în provincia Constantine. Scopul l-a reprezentat monitorizarea managementului efectiv al deșeurilor urbane în cadrul centrului orașului, dezinfectarea și eliminarea deșeurilor solide. Astfel, am monitorizat cele mai importante mijloace prin care autoritățile locale încearcă să elimine deșeurile solide, în principal gropile de gunoi sau incinerarea, întrucât deșeurile din gospodăriile populației se ridică la 2045328 tone/an. Mizeria plutește în continuare în toate cartierele orașului, datorită nepăsării populației și lipsei unei autorități care să asigure un mediu curat și sustenabil.

Cuvinte-cheie: *poluare, managementul deșeurilor, orașul El-Khroub, deșeuri urbane solide, deșeuri inerte, Algeria*

Introduction

The phenomenon of urban pollution is one of the most serious problems that people in the world suffer from, as it causes the spread of epidemics and diseases that threaten their health. Therefore, it is considered as one of the most important issues that concern societies (Shafi, 2005). Moreover, studies made by specialists in the world demonstrate that pollution in underdeveloped countries appears as a result of emissions of the same order of magnitude as industrial sources in northern countries (Liousse & Galy-Lacaux, 2010).

Algeria has experienced a rapid urbanization growth after independence. However, without so many environmental problems related to pollution have emerged in the urban areas (Abdelkebir, 2021). Through its local and regional administrative bodies, Algeria proceeded at overcoming these catastrophic obstacles by enacting laws such as the "Act of 2001 on land management and its sustainable development" (Aliouche, 2017), which clarifies the role of participants and the various devices for preserving the urban environment.

Among the Algerian national objectives are the reduction of the quantities of waste produced and the mitigation of the impact of their disposal on the environment. The Algerian government has envisioned a national environmental strategy that will permit to present the first foundations of sustainable development. Through this work, we decided to take an example of urban pollution in the city of El-Khroub, which is considered an Algerian city of historical and administrative importance, located in the province of Constantine. The aim was to assimilate the subject and attempt to identify the reality of urban waste management in the city, in order to better understand what systems are used for management and elimination and what control bodies are effective.

In order to study the problems, we conducted a field survey in the region and we probed the areas that suffer from household solid waste pollution, attempting to find out how it is managed by visiting the landfills and disposal areas.

Theory and methodology

Review of literature

One of the environmental challenges currently facing urban societies, particularly third world countries, is solid waste. It is an essential factor which leads to the deterioration of the urban environment resulting problems that threaten the safety of society (Chandrappa & Das, 2012) and distorts the urban landscape. The increase of this problem in such countries is due to the growing population, which makes the per capita share of it is increasing annually. In Asia and Pacific regions, for instance, the capita per is estimated 0.5 to 1.4 kg daily according to the United Nations report that examines the increase in waste until 2025.

In developing countries, the amount of waste produced varies from one city to another, depending on several factors, the most essential is population growth. According to statistics, the average annual production of waste is between 180 and 240kg. This is about 1.5 to 2.5 times less than in industrialized countries (Hiligsmann et al., 2006).

Other studies highlight the same point in the third world scrutinizing what makes life conditions poor (Troschinetz & Mihelcic, 2009) including air and water pollution, in addition to the spread of diseases and epidemics in cities such as malaria and asthma (Koné-Bodou Possilétya et al., 2019), particularly in poor and fragile neighborhoods (Hardoy & Satterthwaite, 1991). Thus in some major African cities like Abidjan, the capital of Côte d'Ivoire, we find large accumulations of household solid waste where the accumulated waste reach 53.65% (N'guettia, 2010). According to a study on India (Pappu, Saxena, & Asolekar, 2007), the amount of solid waste accumulated is 960 million tons annually varies from domestic, and industrial to agricultural solid waste. However, many countries have now realized the concept of waste recycling; therefore it is becoming a source of making profits and generating energy under the framework of sustainable waste management (Chandrappa & Das, 2012). For Algeria, the problem of waste persists since the population continues to rise. According to the recent reports of the National Waste Agency (Chandrappa & Das) for 2020, the amount of household solid waste was 13.5 million tons whereas it was just 11 million tons in 2016, and the report expects it to reach 20.5 million tons in 2035 (AND, 2020), while the estimated amount of waste per capita is 0.80 kg/day (AND, 2020).

Algeria has attempted to address this challenge through a series of actions enacting several laws on environmental protection and waste management to achieve sustainable development, including Act No. 01-19 of 12-12-2001 (Loi, 2001), established competent governing bodies such as the National Waste Agency, and set programs and guidelines such as the Municipal Waste Management Guidelines and the Province Waste Management Scheme (PWAGDES) for the safety of environment and the citizens' health.

Extensive investment has also been made in the area of its operation. Since 2002-2017, it has been estimated 88 billion DA (562 271 020,34 euro), of which 41 billion DA (261967199.93) are for collection and transport tools and 37 billion DA (236409406.28 euro) are for waste management structures (waste, technical land-filling, waste dumps). (AND, 2020). But, despite these huge sums and structures distributed throughout the country, Algeria has not yet achieved the designed goals (Khelladi, 2011), given the magnitude of the obstacles it faces.

Research methodology

The present paper tries to capture the reality of third world societies in general, as well as that of Algeria in particular; this approach is carried out by analyzing the previous literature that tackled the issue of the present study, including some articles and books that highlight this reality as a global challenge, considering that the latter affects both first and third world countries.

However, each country has a certain degree of interest. Developed countries have found solutions to waste disposal once and for all, using it to produce energy in a profitable way. However, most underdeveloped countries still suffer from this worsening phenomenon and from their inability to manage it, falling eventually into a circle of dirt, unpleasant odors and disease. Others try to keep pace with technological advances to reduce the phenomenon.

Considering the lack of theoretical approaches and methods to monitor the situation, the field study is an essential step for carrying out this research. This has been conducted through field investigations. We have visited several Algerian bodies, such as the Ministry of Environment and the National Waste Agency, as well as the local municipalities (ElKhroub) and Constantine authorities, beside the technical land-filling centers belonging to the municipality of AlKhroub.

Situation analysis

El-Khroub city is located in the southeast of the province of Constantine and covers an area of 244.65 ha. It is considered as the second agglomeration after Constantine, and it is the best adapted pole to organize the southern part of the province (Benkouachi & Alatou, 2017). It is crossed by major roads at the citywide, CW 175 (ex RN03) and RN 20, which constitutes a connection towards the other states Guelma and Batna (Fig. 1).

It is bounded as follows: (1) CW 175 bypass road to the East; (2) Railway and the national road RN20 to the South; (3) Railway and the national road RN 05 to the West. The study of local climate requires (Djebel-Ouahch and Chettaba) data area, then since the location of the reference station (Constantine) is at an altitude different from the study area, this led us to make corrections of temperature and rainfall. The climatic data were collected from the meteorological services for a period ranging from 1994 to 2004 which are represented in Figure 2.

The study area has a continental climate, hot in summer and cold in winter. Temperate and dry, rainfall is rare in summer but frequent in winter (Boularak, 2003). The rainy period extends from November to March, when the precipitation amount increases and reaches the highest value of 93 mm in January, while the temperature drops to 2.89°C. The dry period extends between March and November, when temperatures are high, reaching 35 C° in August, while rainfall decreases to 4.81 mm in July. As for the prevailing winds in the region, they are cold and dry northwest winds that blow in winter. The southwest wind (sirocco) is hot and often sand-laden in summer. On the other hand, snow is rare in the area.

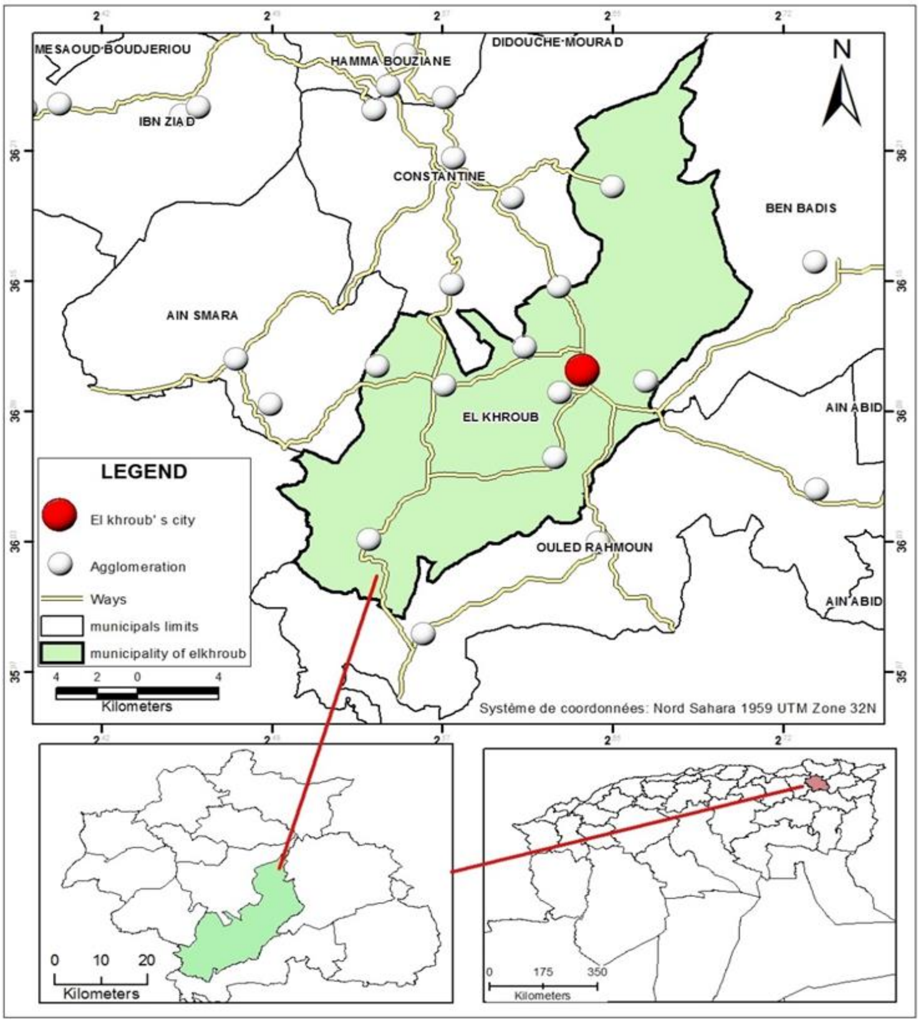


Figure 1: El Khroub city location (State of Constantine)

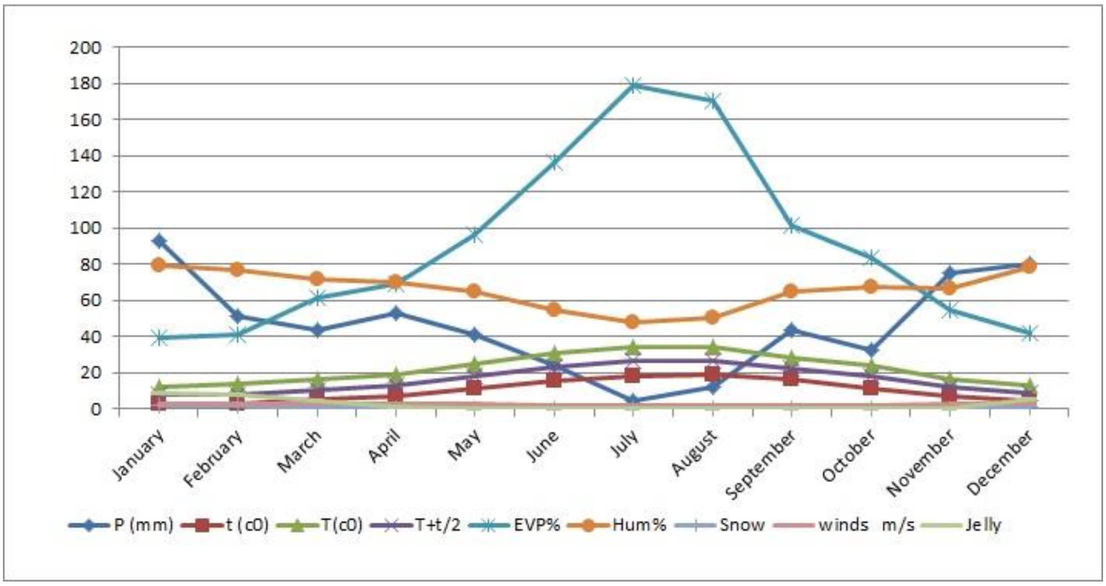


Figure 2: Main climatic characteristics of Constantine during 1995-2004 period (Source: ONM)

The urban growth of the city of El-Khroub is defined through four phases:

- *Phase prior to 1962*: The center of El-Khroub was created by the settlers, who used it as a housing camp and watchtower. It was declared as a seat of the municipality with full disposal by a royal decree of March 28, 1863, extending over an area of 12.5 hectares. The cultural area during this period was 12.5 hectares.
- *Phase from 1962 to 1977*: This stage is characterized by the exodus of the rural populations to occupy the houses of the centenarians. Then, the city of El-Khroub began to expand to the north, east and south, therefore, new neighborhoods appeared, like the district of August 20 which was built in the middle of the city, with about 472 houses, which lacked most of the facilities necessary for life. In addition to The Military Quarter to house the frames of the National Popular Army, to move the city of El-Khroub out of its core on the outskirts in 1974, with 317 dwellings. The urban area at this stage reaches 28.25 hectares.
- *Phase from 1977 to 1987*: This stage witnessed a significant increase in the annual growth rate, reaching 9.45%. Thus, the northern residential urban area emerged in the form of residential neighborhoods such as the neighborhood of 450 apartments, and the 900 apartments, located in north of the old core.
- *Phase from 1987 to 2008*: It was distinguished by the completion of the remaining projects from the previous period: the neighborhood of 300-apartments belongs to 900-unit apartments sector, the neighborhood of 500 apartments belongs to 1600 apartments, and the 500 apartments belongs to 1200 apartments (Marouk, 2008). After 1998, the authorities reassessed the situation through the publication of the Directive for Development and Reconstruction for the Constantine’s assembly before launching major projects towards the new town of Masinissa on an area of 235 Ha.
- *Phase from 2008 to 2016*: The establishment of various facilities varying between shops and real estate agencies of which the most important are: the financial center, the foreign bank, the commercial bank and the cultural center, furthermore the youth center and the construction of a new departmental headquarters with the continued completion of housing projects in addition to the creation of a new city Masinissa in the northeast and the city Ain-Nahas in the north-west of the municipal center and the new city in Ali Mendjeli in the west.

Results and discussion

Reality of urban waste management in the city of El-Khroub

Types of municipal waste

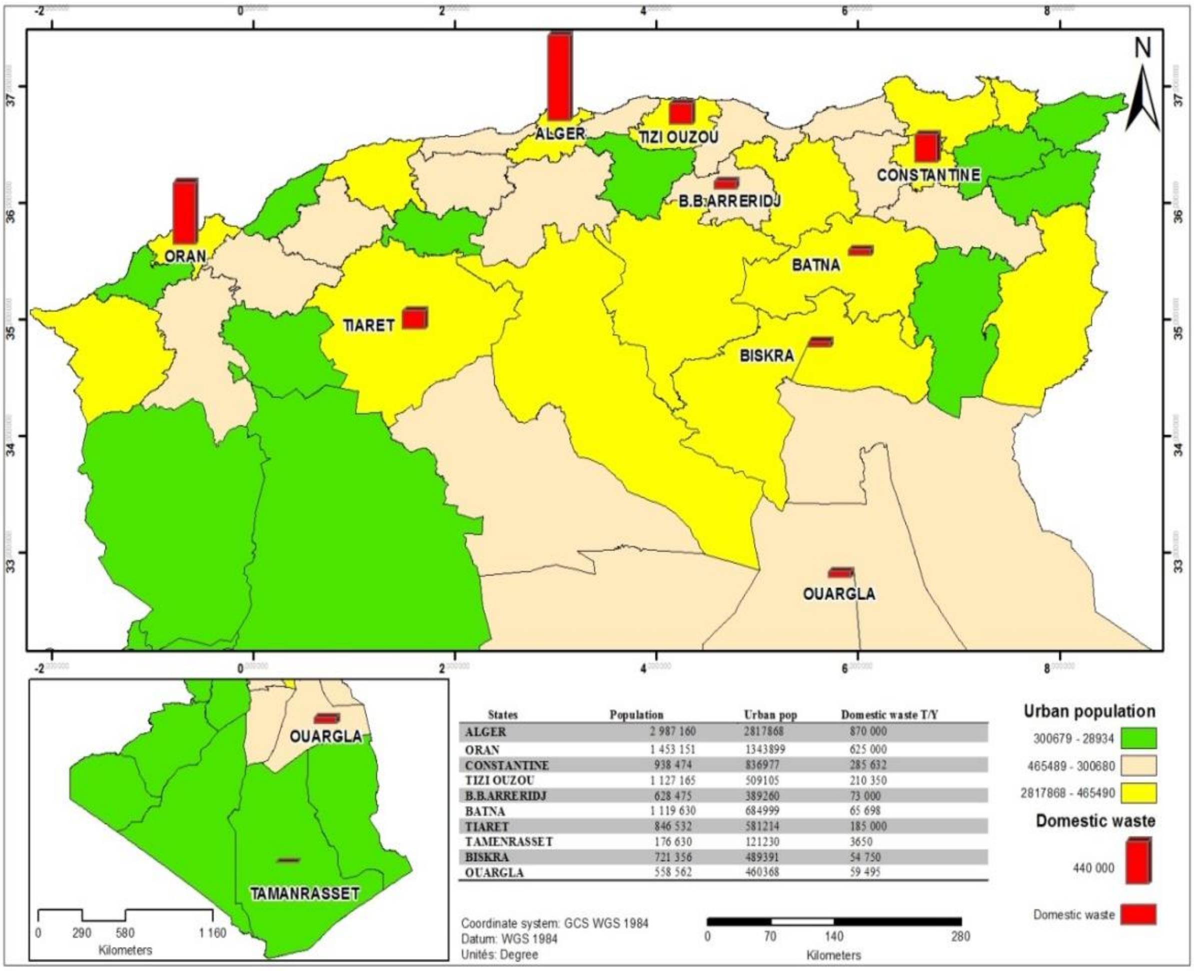
Waste is defined as “any residue of a production process of transformation, or use any substance, material, product or more generally, any movable property abandoned or which its holder intends to abandon” (Thürer et al., 2017). This definition to the waste presents harmful effects on the ground, the flora and the fauna, degrading the sites or the landscapes, generating noises or odors and attacking human health and environment (Mwangi & Thuo, 2014). These definitions therefore include household waste as well as industrial residues and unused products from agriculture (Damien, 2004).

From the general definition of waste, we then decline their different categories by taking into account certain aspects of waste: hazardous or not, physical, chemical and biological characteristics (fermentable, flammable, etc.) producing sector (industries, private community), composition, use (packaging, household appliances, vehicle) (Balet, 2016).

Household and similar waste

The term "Household and Assimilated Waste" includes the Household Waste, which comes from the domestic activity of the households as well as the waste coming from the industries, craftsmen, tradesmen, schools, public services and hospitals (Lebersorger & Schneider, 2011).

It usually consists of materials left over from the family's daily use, which includes organic materials from vegetable and fruit scraps, bread and others, in addition to plastics, glass, paper, cardboard, leather, metals, etc. These components differ in weight of the total waste product from one area to another within the same city. Indeed, in Algeria, the problem persists. In 2020, according to AND, the quantity of treated household waste was evaluated at 6 million tons, that is to say, a treatment rate of 45% compared to the total quantity generated, estimated at 13.5 million T (AND, 2021). As a result, the installed capacity for waste treatment is not sufficient. The following figure gives a picture of the quantity of waste produced in some provinces of Algeria.



States	Population	Urban pop	Domestic waste T/Y
ALGER	2 987 160	2817868	870 000
ORAN	1 453 151	1343899	625 000
CONSTANTINE	938 474	836977	285 632
TIZI OUZOU	1 127 165	509105	210 350
B.B.ARRERIDJ	628 475	389260	73 000
BATNA	1 119 630	684999	65 698
TIARET	846 532	581214	185 000
TAMENRASSET	176 630	121230	3650
BISKRA	721 356	489391	54 750
OUARGLA	558 562	460368	59 495

Coordinate system: GCS WGS 1984
Datum: WGS 1984
Unités: Degree

Figure 3: Production of domestic waste in relation to population in Algeria (Source: RGPH 2008 and AND 2017)

It should be noted that the cities on the Algerian coast, which are more densely populated, generate much higher quantities of waste than those in the highlands and the South (Abdelli, 2017). The province of Algiers produced more than 870000 tons in 2017, followed by the province of Oran, with a production of 625000 tons per year. The average city emits between 200 and 300000 tons of waste per year. particularly this is the case of Constantine in the East and Tizi-Ouzou in the Center. Indeed, some cities produce amounts of less than 50000 tons of waste per year, which are generally concentrated in the South; this is the case of Biskra and Ouargla, which are characterized by a low population density. As for the South, the province of Tamanrasset emits 3650 tons of waste per year (Eddine, 2012).

Following the AND report, 89 CET were installed in the northern region, and highlands and 81 controlled dumps, or 90% of the total national park. The rest is located in the South region with 12 CET and 09 controlled landfills, that is 10% of the total number (AND, 2021).

The quantity of domestic waste deposited in El-Khroub city, in 2017 is estimated at 20453.28 tons (source: EPCA 2017). It is noted the rapid increase in the amount of household waste in 2014, as it increased in one year by about half of the first amount in 2013, which was estimated at 20500.00 tons. The year 2016 reached 44000,00 tons at the maximum. Then it recorded a decline in 2017, which was estimated at 20453,28 tons. This decline can be attributed to the strategy implemented by the State and local authorities to manage and reduce this waste. The situation becomes unmanageable when cleaning staff strike for more than 10 days (Ter, 2020) to demand their social and professional needs. This leads to the accumulation of piles of waste on the streets, especially as local authorities procrastinate in solving this often recurrent problem that threaten public health

Figure 4: Domestic waste in El Khroub city (1600 housing district) (Source: the authors)

Inert waste

Inert waste is not subject to any significant physical, chemical or biological modification. It consists mainly of construction waste: excavations and debris; demolition waste with treated wood, free asbestos, tar paints, pyralene (Kourmpanis et al., 2008). The city of El-Khroub suffers from the problem of inert wastes, which has deformed its urban environment and resulted from construction and restoration work such as bricks, ceramics, bricks, earth and statistics, concrete, ... etc. In addition to the cutting branches of trees, the amount of inert wastes produced is now estimated at 9 tons per year. The presence of various types of waste in the vicinity of the population often leads to many health and social pathologies.

Municipal Abattoir of El-Khroub city

The workers of the municipal abattoir unload the amount of waste, including the remains of entrails and their contents, into a trailer with a capacity of 10 tons, where they are collected by the public institution of cleaning and disinfection, which has an agreement with the abattoir, two times a week*.* On the day of Eid al-Adha (the feast of Muslims), the amount of solid household waste can reach 500 tons in the city of Al-Khroub alone.

Figure 5: The inert waste at El Khroub city (Source: the authors)

Waste management actors

Waste management in Algeria is carried out by two sectors: the public sector (the municipality) and the private sector (Sakri et al., 2021).

The public sector (the municipality)

The Algerian legislator has recognized that responsibility for the management of household and similar waste lies with the municipality, which must organize on its territory a public service to meet the collective needs of its citizens in terms of collection of household and similar waste, its transport and its treatment.

It is also possible for two or more municipalities to join to participate in the management of part of the household waste, this was confirmed by article 03 of decree n°84-378 of December 15, 1984: "The municipal People's Assembly organizes, under the conditions provided for in this chapter, on its own territory, or in common, or through common municipal bodies, or in an appropriate manner the collection service of waste requiring a particular organization: industrial waste, radioactive waste, fecal matter" (official journal, 1984)

The local public establishment of cleaning and disinfection of the town of El-Khroub

The municipality of El-Khroub signed an agreement with the local public institution of cleaning and disinfection in 1989, renewable annually, to ensure the maintenance of cleanliness and sanitation of the entire soil of the municipality. It is an establishment of an industrial and commercial nature, with legal personality and financial independence, created by the community (Municipal Council) on March 07, 1988. The legal status or capacity of the establishment has been changed from a public economic establishment (EPE) to an industrial and commercial establishment (EPCA), in accordance with State Decree n°130 of 08/09/2011.

This establishment is located in Ben Boulaid district in El-Khroub, on an area of about one hectare. It enjoys financial autonomy for the management of household waste. It also works hard to collect, sweep and transport household waste and similar on almost the entire municipal territory. It is responsible for:

(1) collection of household and similar waste; (2) Sweeping of streets, roads, and highways; (3) Cleaning of public places and parks; (4) Lifting of rubble; (5) Collection of hospital waste; (6) Mosquito control by burying the carcasses of dead animals, according to Article 19 of Decree No. 88 corresponding to 15 December 1984 (official journal, 1984)

(2) *Urban solid waste disposal centers in the city of El-Khroub*: The first official regulation of this style of *waste* management dates back to the 5th century B.C, when the authorities of the city of Athens, Greece, decreed that all waste must be transported more than one mile (1.6 km) from the city limits. The city of El-Khroub has known several public waste disposal facilities to get rid of its urban solid waste, which are:

(3) *El-Haria Landfill*: The landfill of El-Haria is located on the national road n°111 leading to Constantine in an area called "Al-Qashqash". The landfill is 5 km from the town of Ben Badis and 20 km from the headquarters of the town of El-KhroubThe dump is located on a slope surrounded by agricultural land, 5 km north of the dump (Mansouri et al., 2018). The waste has been dumped there since 2001. The area allocated to the farm is 5 hectares.

(4) *public waste disposal centre "Ain Smara"*: It is located at the top of a private quarry - Hodna Ibrahim - in Djebel Awlad Salam, 4 km from the municipality of Ain Smara, and 5 km from the national road 101 (Fig.8). The use of the public waste disposal site started in 1992, it receives waste from the municipality of Ain Smara, El-Khroub, the public fruit and vegetable markets of Constantine and the production unit of Saïdal (AMRI, 2007).

(5) The dumping of garbage in the city of El-Khroub began in 2005. The waste is emptied without any regulation and directly on the roadside. Furthermore, the surface area of the landfill is estimated to be 4 hectares, the area operated is 2 hectares and the amount of waste dumped in the landfill is estimated to be 60 tons/day. The dump reached its saturation point within 5 years, when it was closed in 1997, in May 2004, the dump was reopened with an area of 7 hectares.

(6) *the "Bougherb" Technical Landfill Center (CET)*: in accordance with the law 01-19 of December 12, 2001 (Official journal. 2001), relating to the management, control, and elimination of waste. The technical landfill center is an alternative to the common public dumpsters in order to prevent and preserve the environment, taking into account the exact operating conditions of the technical landfill center.

(7) *The first CET in Algeria was built in 2000 in Ouled Fayet* (Djadia et al., 2008), in the periphery of Algiers, five watertight pits were built, as well as a drainage system. Indeed, the realization of the CET is a main axis, then the Algerian State devoted considerable investments to realize them. Nowadays, 221 treatment installations have been built, 191 of which are in progress (AND, 2021).

(8) According to environmental specialists, the construction of a CET requires an area of not less than 40 ha, fenced, and landscaped. The first of the constraints facing the realization of the national program of CET is the problem of expropriations and opposition from residents, according to the government (Ahoussi et al., 2011).

(9) *The CET Bougherb is located in Ben Badis municipality* (Fig.7), which is located at east of the city of Constantine, 40 km (Ayat et al., 2021). The area contains sandy rocks, to the west of the site of Al-Qashqash consisting of gravel and clay, to the south, limestone massif of Mount Amestas, to the east and south-west, caritas limestone, to the extreme north-west we find formations consisting of marl and conglomerate.

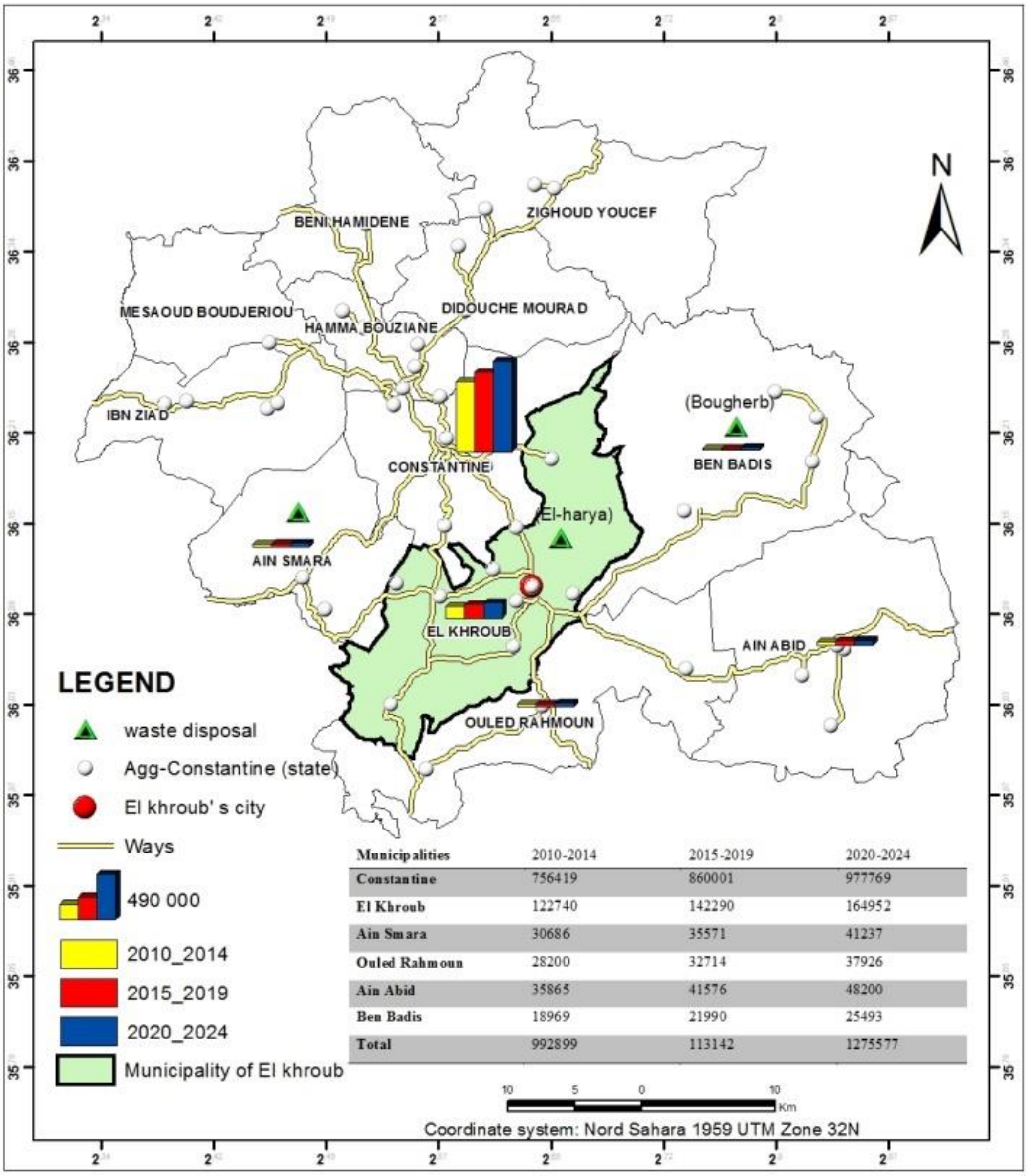
Figure 6: Part of the garbage collection process in El-Khroub city

Figure 7: CET Bougherb at Ben Badis from 2004 to 2021 (36°18'22.7N 6°51'15.0E) (Google Earth)

This figure (Fig.7) shows the construction stages of the landfill site since 2004, it also shows the different components of the landfill (Sorting place; Maintenance workshop; Retention Basins; Landfill Site). In 2021 it seems that it is functional and effective to managing waste.

We note that the amount of waste is constantly increasing, reaching the largest amount in the municipality of Constantine 860001T/year in 2019, followed by the municipality of El-Khroub of 142,290 tons/year, this is due to the expansion of the area of the municipality and the high number of residential areas, as well as the various organizations.

The quantity of municipal waste in Constantine is constantly increasing, according to the statistics of the waste disposal centers, as they confirm the continuation of the increase until 2024 (Fig. 8).



Municipalities	2010-2014	2015-2019	2020-2024
Constantine	756419	860001	977769
El Khroub	122740	142290	164952
Ain Smara	30686	35571	41237
Ouled Rahmoun	28200	32714	37926
Ain Abid	35865	41576	48200
Ben Badis	18969	21990	25493
Total	992899	113142	1275577

Figure 8: Location of public waste disposable Centers of El-Khroub city and Amount of waste landfilled since 2010 and planned for 2020-2024 (Source: The Public Organization for the Management of Technical Landfills and Waste Treatment Centers, 2019)

Household waste treatment methods

The city of El Khroub has suffered a lot from illegal dumps in the roadside, as they represented in the long term a public danger.

Landfill

The bottom of the cells is lined with layers of compacted clay and high-density plastic films, which provide a watertight seal to prevent liquid effluents from seeping into the soil. Furthermore, the waste is compacted in huge pits called lockers and then buried under layers of soil. The preparation process of the funeral center is based mainly on the creation of a watertight cell that allows its progressive filling.

Figure 9: Garbage storage in the CET Bougherb (Ben Badis)

The cell is filled according to a scheme that determines its operation, as well as compensatory measures to preserve the environment. Before starting to fill the cell, the bottom is cleaned of all weeds, then a layer of clay is well placed compacted to a thickness of 75 cm, then covered with a non-permeable membrane called (the geomenbrane), which are membranes usually made of Polyethylene of high density or low density PVC, VFPE, HDPE, the geomenbrane is fixed with a mound of soil, which is then spread (Albright et al., 2006).

A second layer called Geotextil is added to avoid holes when the waste and machinery pass through. As a third layer, the Geodrain has the particularity of placing the evacuation tubes (drain pipe) of the LIXIVIAT (leachate) resulting from the residual liquid formed by the water running through the waste (Fleming & Rowe, 2004). This water is collected in a filtration storage tank and then transferred to a water filtration plant, where the treatment is carried out by the Lagunage technology due to its simplicity and low cost. Besides, the waste placed in the form of slicks in the deepest compartment of the cell is exposed to anaerobic fermentation, which is accompanied by the emission of biogas (Hashimoto, 1982), these gases are concentrated deep in the cell in the form of methane, which leads to serious accidents in the event of leakage into nature, can lead to the death of many animal and plant organisms.

The BIOGAS is eliminated by discharging it using several flares where they are placed inside a perforated cement tube, the distance between one flare and another is between 40-50m. It is also necessary to monitor the emission of methane gas above the CET because it causes accidents and explosions if its level exceeds 5% in the air (Zamorano et al., 2007). For the design of CET, certain conditions are taken into consideration such as site topography, geology and hydrogeology (Badjenna et al., 2016). According to the land use maps of the municipality of Ben Badis, the CET is placed in a bare land surrounded by a large agricultural area (Gana et al., 2018), a water lake is far from the landfill by a distance of 3 Km as the crow flies (Google earth). Thus, it is necessary to put very serious measures to avoid the filtration of water, especially as the region can experience a rather important wet period according to the analysis of Figure 2.

Waste incineration (or thermal treatment)

Incineration is one of the simplest techniques of disposal of urban waste. It is the process of being destroyed by fire, however due to their different components; they contain elements that are difficult to burn (Rand, 2000).

This operation allows us to: (1) Reduction of waste volume by 70-90%; (2)Valorization of the heat produced by combustion into district heating or electricity; (03)Incineration of municipal solid waste eliminates pathogenic organisms ; (4)It may be the only method that can be followed when there is no space required for a sanitary landfill or when groundwater is close to the surface; (05)To be operated as an optimal means of disposing of special and hazardous municipal solid waste such as hospital waste and abattoir waste. Incineration leads to the formation of thousands of molecules of only a fraction which is systematically searched in the fumes that cause some diseases (Council, 2000), such as liver, digestive tract and blood cancer due to dioxin exposure (Wissing, 2005).

In Algeria, currently, the solution of incineration is applied only for hospital waste within hospitals. For the following disadvantages: (1) very high humidity rate, (2) higher treatment cost due to equipment and operation costs, (3) the predominance of organic waste in the household waste (Wissing, 2005).

Recycling (or material recovery)

According to the services of the Ministry of Environment and Water Resources, Algeria has the capacity to recover a quantity of waste estimated at 760000,00 tons per year, which represents 3.5 billion Da (22304149,98 euro), of which paper represents an essential part in the possibility of recovery and recycling with a quantity of 385000,00 tons per year (the system of recovery of unsold newspapers). Out of more than 2 million tons of plastic packaging produced in Algeria by 192 units, only 4,000 tons are recovered (i.e. 0.0002%) (AND, 2021).

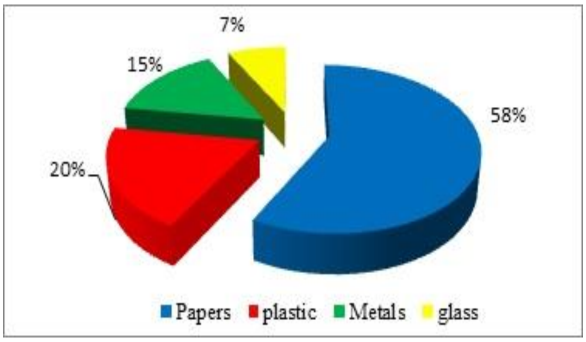


Figure 10: Types of recyclable waste in Algeria in 2017 (source: AND)

According to a publication by Tonic Emballage, a company specializing in the production of packaging in Algeria, the recycling capacity of the Algerian paper industry does not exceed 10% of all waste generated annually, while national consumption of paper and cardboard is estimated at 600000,00 tons / year Nearly 335000,00 tons of waste are dumped annually (Djemaci & Zaïd-Chertouk, 2011).

Recycling is possible for cardboard, paper, glass, plastic, metals, and dangerous household waste (batteries, paint, oil, etc.). The economic and environmental benefits of recycling are considerable (Pimentel, 1997), it helps to: (1) protect natural resources; (2) reduce waste; (3) create jobs, (4) protect nature and save raw materials (Oke & Kruijsen, 2016). Algeria has 39 sorting sheds and 11 operational sorting centers (AND, 2021).

Figure 11: Storage of recoverable waste in El Khroub

During the meeting with the director of the environment of the province of Constantine, he said that the city of El-Khroub has an urban management establishment in the new city Ali-Mendjeli (EGUVAM) which has realized a selective sorting centre since April 2017. Its objective is the collection and recycling of dry household waste. This amount is part of a total of 30 tons of this type of waste, collected during this period through 19 neighborhood units in city of Ali-Mendjli, with an average collection of 580 kg/day, As the average recycling per day of waste of various types including bottles and plastic bags, is estimated at 150 kg.

Composting (biological recovery)

Composting is a biological process of transformation of organic waste (kitchen, green and wood wastes) by microscopic fungi and bacteria into a product comparable to soil (Insam et al., 2007).

The environmental benefits are multiple: (1) decrease the use of chemical fertilizers from mining resources (potash, phosphorus) by replacing them with natural composts; (2)reduce the amount of waste disposed of in landfills or incineration;(3) contribute to the reduction of greenhouse gases generated by waste treatment (incineration for example) (Wei et al., 2017).

Impact of municipal solid waste

Despite the laws in force within the city of El-Khroub for the disposal of waste, we notice huge amounts of waste scattered everywhere (Fig.12), causing a number of effects of which the most important are:

(1) Leaving waste, especially organic materials, in the streets or chaotic dumps under external influences, which makes it vulnerable to rotting and causes the escape of unpleasant odors. It is also a breeding ground for insects, which transmit many diseases to humans.

(2) Distorting the aesthetic view of the city.

(3) The volume of waste exceeds the containers, and in many and most cases, the waste is dumped in an unorganized and irrational manner, leading to the pollution of the city's external environment.

(4) Unpleasant odors emitted from waste inside open containers, or dispersed in random locations.

Figure 12: Neglected waste in the districts of El Khroub city

Conclusion

Through our field study and the analysis of various data and statistics related to the reality of waste in the city of El-Khroub, we conclude that the city suffers from the spread of waste of all kinds, especially household waste, which is associated with an increase in the size of the population of the region.

In spite of the presence of organisms charged by the elimination of the diverse types of wastes, but, the definitive elimination of this dirt has become almost impossible, considering the disinterest experienced by the citizen, and the little importance given to the necessity of preserving the environment by controlling all those responsible for the chaos in the urban space.

However, the following steps should be taken:

(1) Place large containers to accommodate the amount of household waste;

(2) Use good bags to pick up litter so that it does not tear easily due to the spread of stray cats and dogs in the litter box;

(3) Enact strict laws and penalties against anyone who pollutes urban areas;

(4) Perform road washing at night to get rid of volatile waste and unpleasant odors;

(5) Conduct awareness-raising operations among citizens and encourage them to dispose of their garbage in a legal and clean manner, by disposing of it in designated places and not randomly;

(6) Educate children in schools and the love of cleanliness;

(7) Hold contests for the best neighborhood award. These incentives work well and encourage citizens to keep their neighborhoods clean;

(8) The State shall ensure waste separation by placing specialized containers for materials, such as glass, plastic, paper, and other waste, to recover what can be recycled.

Funding

This research received no external funding.

Acknowledgements

The authors are grateful to the editor and the anonymous reviewers for their valuable comments and helpful suggestions.

Author contribution

This work was a joint work, each researcher put his trace. naziha LAMRI and Amna BELAYADI thought on the subject treated, faiza ABBAS carried out the methodology as she collected statistics from different directions, we shared the plan of work between us and each author took his share of drafting to finish as early as possible and after we made revision sessions together. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Abdelkebir, B., Maoui, A., Mokhtari, E., Engel, B., Chen, J., & Aboelnour, M. (2021). Evaluating Low-Impact Development practice performance to reduce runoff volume in an urban watershed in Algeria. *Arabian Journal of Geosciences, 14*(9), 1-10. https://doi.org/10.1007/s12517-021-07178-0

Abdelli, I., Asnoune, M., Arab, Z., Abdelmalek, F., & Addou, A. (2017). Management of household waste in sanitary landfill of Mostaganem district (Western Algeria). *Journal of Material Cycles and Waste Management, 19*(1), 265-281. doi: https://doi.org/10.1007/s10163-015-0415-6

Ahoussi, K. E., Oga, Y. M. S., Koffi, Y. B., Kouassi, A. M., Soro, N., & Biemi, J. (2011). Caractérisation hydrogéochimique et microbiologique des ressources en eau du site d'un Centre d'Enfouissement Technique (CET) de Côte d'Ivoire: cas du CET de Kossihouen dans le District d'Abidjan (Côte d'Ivoire). *International Journal of Biological and Chemical Sciences, 5*(6), 2524-2542. doi: 10.4314/ijbcs.v5i6.32

Albright, W. H., Benson, C. H., Gee, G. W., Abichou, T., Tyler, S. W., & Rock, S. A. (2006). Field performance of three compacted clay landfill covers. *Vadose Zone Journal, 5*(4), 1157-1171. doi: https://doi.org/10.2136/vzj2005.0134

Aliouche, S., Kehila, Y., & Benkahoul, L. (2017). Modalités de sélection des sites d'enfouissement technique en Algérie et leur prise en charge par les instruments d'aménagement du territoire et d'urbanisme. *Déchets Sciences et Techniques, 75*, 1-10. doi: https://doi.org/10.4267/dechets-sciences-techniques.3696

Allen, A., & Taylor, R. (2006). Waste disposal and landfill: control and protection. *Protecting groundwater for health: managing the quality of drinking-water sources*, 631-652. https://eid.episciences.org/7770

Amri, B. (2007). Pollutions et nuisances dans la ville de Constantine: effets et impacts sur l'environnement. *Sciences & Technologie. D, Sciences de la terre*, 21-30. https://and.dz/5999-2/

AND. (2021). Report on the State of Waste Management in Algeria. https://and.dz/rapport-sur-letat-de-la-gestion-des-dechets-en-algerie/

Ayat, A., Arris, S., & Meniai, A. (2021). *Landfill Leachate Pretreatment by Coagulation/Flocculation Process: Optimization by response surface methodology.* Paper presented at the 2021 12th International Renewable Energy Congress (IREC).

Badjenna, Z., Kounda, Z., & Habchi, A. (2016). *Etude de faisabilité technique de la valorisation des déchets ménagers par enfouissement technique cas CET Wayenna-Adrar.* Université Ahmed Draïa-Adrar.

Balet, J.-M. (2016). *Gestion des déchets*: Dunod.

Benkouachi, N. E., & Alatou, D. (2017). Le sig et la gestion des espaces verts de la ville d'elkhroub. *Sciences & Technologie. C, Biotechnologies*, 17-24.

Boularak, M. (2003). Etude hydrogéologique du bassin versant de Boumerzoug. *Vulnérabilité des eaux souterraines et impact de la pollution sur la région d'El Khroub. Mémoire de Magister (Hydrogéologie). Université des frères Mentouri-Constantine1.*

Çeçen, F., & Çakıroğlu, D. (2001). Impact of landfill leachate on the co-treatment of domestic wastewater. *Biotechnology letters, 23*(10), 821-826.

Chandrappa, R., & Das, D. B. (2012). *Solid waste management: Principles and practice*: Springer Science & Business Media.

Council, N. R. (2000). Waste incineration and public health.

Damien, A. (2004). *Guide du traitement des déchets*: Dunod Paris. https://www.dunod.com/sites/default/files/atoms/files/9782100747191/Feuilletage.pdf

Djadia, l., abtout, a., baker, h. A., fahem, a., iken, h., bouabdellah, h., . . . Machane, d. (2008). Apport des méthodes géophysiques dans l'évaluation d'un risque environnemental de pollution induite par une décharge urbaine: la décharge d'ouled fayet, alger. *Bull. Serv. Géol. Nat. Vol, 19*(2).

Djemaci, B., & Zaïd-Chertouk, M. A. (2011). La gestion intégrée des déchets solides en Algérie. Contraintes et limites de sa mise en oeuvre. *Working Paper CIRIEC, 4*, 3-66. http://www.ciriec.uliege.be/wp-content/uploads/2015/08/WP11-04.pdf.

Dorbane, N., & née Chikh, S. A. (2009). Interaction développement durable et gestion des de-chets: application a l'économie Algerienne. *Revue de l'Algerian Petroleum Institute, 3*(02), 43. https://www.asjp.cerist.dz/en/downArticle/225/3/2/21275.

Eddine, B. T., & Salah, M. M. (2012). Solid waste as renewable source of energy: current and future possibility in Algeria. *International Journal of Energy and Environmental Engineering, 3*(1), 1-12. https://doi.org/10.1186/2251-6832-3-17

Fleming, I., & Rowe, R. (2004). Laboratory studies of clogging of landfill leachate collection and drainage systems. *Canadian Geotechnical Journal, 41*(1), 134-153. https://doi.org/10.1139/t03-070

Gana, M., Bendarradji, M., & Alatou, D. (2018). Intégration of Geomatics for Monitoring Agro-Sylvo-Pastoral System Dynamics: A case study of Ben Badis, Constantine, Algeria. Application de la Géomatique au Suivi de la Dynamique de Système Agro-Sylvo-Pastoral: Cas de la Région de Ben Badis, Constantine, Algérie. https://scholar.archive.org/work/gunzsq6bg5dmrfzroejxyr4obi/access/wayback/http://www.jnsciences.org/index.php?option=com_attachments&task=download&id=452

Hardoy, J. E., & Satterthwaite, D. (1991). Environmental problems of Third World cities: a global issue ignored? *Public administration and development, 11*(4), 341-361. https://doi.org/10.1002/pad.4230110405

Hardoy, J. E., & Satterthwaite, D. (1991). Environmental problems of Third World cities: a global issue ignored? *Public administration and development, 11*(4), 341-361. https://doi.org/10.1002/pad.4230110405

Hashimoto, A., Robinson, S., Klink, R., & Ham, R. (1982). Performance of a pilot-scale, thermophilic, anaerobic fermenter treating cattle waste. *Resources and conservation, 8*(1), 1-41. https://doi.org/10.1016/0166-3097(82)90049-9

Hiligsmann, S., Lardinois, M., Diabaté, S., & Thonart, P. (2006). Guide pratique sur la gestion des déchets ménagers et des sites d'enfouissement technique dans les pays du Sud. https://hdl.handle.net/2268/12919

Insam, H., & De Bertoldi, M. (2007). Microbiology of the composting process *Waste management series* (Vol. 8, pp. 25-48): Elsevier. https://doi.org/10.1016/S1478-7482(07)80006-6

Khelladi, M. A. M. (2011). La refonte du système algérien de gestion des déchets urbains pour une internalisation optimale des externalités environnementales: l'écologie industrielle (EI) comme alternative. *Maghreb-Machrek*(3), 81-94. DOI : https://doi.org/10.3917/machr.209.0081

Koné-Bodou Possilétya, J., Kouamé, V. K., Fé Doukouré, C., Yapi, D. A. C., Kouadio, A. S., Ballo, Z., & Sanogo, T. A. (2019). Risques sanitaires liés aux déchets ménagers sur la population d'Anyama (Abidjan-Côte d'Ivoire). *VertigO-la revue électronique en sciences de l'environnement, 19*(1).doi : https://doi.org/10.4000/vertigo.24417

Kourmpanis, B., Papadopoulos, A., Moustakas, K., Stylianou, M., Haralambous, K., & Loizidou, M. (2008). Preliminary study for the management of construction and demolition waste. *Waste Management & Research, 26*(3), 267-275. https://doi.org/10.1177/0734242X07083344

Lebersorger, S., & Schneider, F. (2011). Discussion on the methodology for determining food waste in household waste composition studies. *Waste management, 31*(9-10), 1924-1933. https://doi.org/10.1016/j.wasman.2011.05.023

Liousse, C., & Galy-Lacaux, C. (2010). Pollution urbaine en Afrique de l'Ouest. *La météorologie*.

Loi. N 01-19 du 12 décembre 2001. *Journal officiel Algérie*. https://lameteorologie.fr/admin/api/public/api/meteo/website/downloadArticlePDF/meteo_2010_71_45.

Mansouri, N., Assabaa, R., & Bennadji, K. (2018). The impact of EL HARIA technical landfill on the environment: degradation of microbiological water quality. *Journal of new technology and materials, 8*(2), 83-93.

Marouk, M. (2008). éclatement spatial et fonctionnel d'une ville cas d'el Khroub. *Sciences & Technologie. D, Sciences de la terre*, 65-70. http://revue.umc.edu.dz/index.php/d/article/view/481.

Mwangi, M. W., & Thuo, A. D. M. (2014). Towards conceptual and theoretical foundation for identifying problems, challenges and mechanisms for municipal waste management in developing countries. http://hdl.handle.net/123456789/6881

N'guettia, K. (2010). Gestion des ordures ménagères d'Abidjan: Diagnostic. *Mémoire de master spécialisé en génie sanitaire et Environnement, Fondation 2ie, Burkina Faso*.

Official journal. (1984). n°66. https://www.joradp.dz/HFR/Index.htm

Official journal. (2001). n°76. https://www.joradp.dz/HFR/Index.htm

Oke, A., & Kruijsen, J. (2016). The importance of specific recycling information in designing a waste management scheme. *Recycling, 1*(2), 271-285. https://doi.org/10.3390/recycling1020271

Pappu, A., Saxena, M., & Asolekar, S. R. (2007). Solid wastes generation in India and their recycling potential in building materials. *Building and environment, 42*(6), 2311-2320. https://doi.org/10.1016/j.buildenv.2006.04.015

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., . . . Cliff, B. (1997). Economic and environmental benefits of biodiversity. *BioScience, 47*(11), 747-757. https://doi.org/10.2307/1313097

Rand, T., Haukohl, J., & Marxen, U. (2000). *Municipal solid waste incineration: Requirements for a successful project* (Vol. 462): World Bank Publications.

Sakri, A., Aouabed, A., Nassour, A., & Nelles, M. (2021). Refuse-derived fuel potential production for co-combustion in the cement industry in Algeria. *Waste Management & Research, 39*(9), 1174-1184. https://doi.org/10.1177/0734242X20982277

Shafi, S. (2005). *Environmental pollution*: Atlantic Publishers & Dist.

Thürer, M., Tomašević, I., & Stevenson, M. (2017). On the meaning of 'waste': review and definition. *Production Planning & Control, 28*(3), 244-255. https://doi.org/10.1080/09537287.2016.1264640

Ter, I. (2020). Les agents de collecte en grève depuis 15 jours, la ville croule sous les ordures. Le soir d'Algérie, https://www.lesoirdalgerie.com/regions/les-agents-de-collecte-en-greve-depuis-15-jours-la-ville-croule-sous-les-ordures-45942

Troschinetz, A. M., & Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. *Waste management, 29*(2), 915-923. https://doi.org/10.1016/j.wasman.2008.04.016

Wei, Y., Li, J., Shi, D., Liu, G., Zhao, Y., & Shimaoka, T. (2017). Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. *Resources, Conservation and Recycling, 122*, 51-65. https://doi.org/10.1016/j.resconrec.2017.01.024

Wissing, M., Dor, P., Pana, A., Ralet, J., & Piérart, P. (2005). Les effets de l'incinération des déchets sur la santé. *Une, 18*, 19. http://www.synec-doc.be/alt/bempt/diox03.html

Zamorano, M., Perez, J. I. P., Paves, I. A., & Ridao, A. R. (2007). Study of the energy potential of the biogas produced by an urban waste landfill in Southern Spain. *Renewable and Sustainable Energy Reviews, 11*(5), 909-922. https://doi.org/10.1016/j.rser.2005.05.007

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **172-185**
http://dx.doi.org/**10.5775/fg.2022.217.d**

Ecosystem behavior face to climatic changes and anthropogenic actions. Case study: a north-eastern urban wetland, Tunisia

Faiza Khebour ALLOUCHE[1,2,*], Rania AJMI[1,2], Safa Belfekih BOUSSEMA[1,2], Gheorghe ȘERBAN[3]

[1] High Institute of Agronomic Science of Chott Mariem (ISA-CM), Sousse University, B.P 47.4042 Chott Meriem Sousse-Tunisia
[2] National Agronomic Institute of Tunis, Lr GREEN TEAM (LR17AGR01), Carthage University, B.P 43, Avenue Charles Nicolle 1082 Tunis Mahrajène-Tunisia
[3] Babeş-Bolyai University, Faculty of Geography, 5-7 Clinicilor, 400006, Cluj-Napoca, Romania
* *Corresponding author*: allouchekhebour@yahoo.fr

Received on 02-07-2022, reviewed on 12-08-2022, accepted on 30-09-2022

Abstract

Wetlands environments are ecosystems threatened by climate change and urban sprawl. Studying the behavior of Sabkhaof Sousse, the green lung of the industrial region of Sidi Abd Elhamid in north-eastern Tunisia, is necessary to improve the living conditions of the population living within this ecosystem. This study analysis the impact of climate change and human activities on the seasonal and pluriannual behavior of this Sabkha by using multitemporal series of high-resolution satellite imagery, and a survey among the inhabitants of the area. Shorelines from 2003 to 2019 were vectorized in GIS environment using georeferenced images from Google Earth platform. Then, Land Use Land Cover changes were detected by using Environment Visualizing Imageries software. Results show that built-up and cultivated areas have increased by 4.3 % and 18.5 % respectively in the North and East side of the study area. Moreover, climatic changes during the seasons lead to changes in the soil occupation. Hence the importance of setting up strategies to preserve this brittle ecosystem. The development of an urban park around the Sabkha will enhance the local population's living conditions while also protecting the Sabkha from degradation.

Keywords: *urban wetland, climate change, Land Use Land Cover, population well being*

Rezumat. Comportamentul ecosistemului în fața schimbărilor climatice și acțiunilor antropice. Studiu de caz: o zonă umedă urbană din nord-estul Tunisiei

Mediul terenurilor umede reprezintă ecosisteme amenințate de către schimbările climatice și extinderea urbană. Studierea comportamentului Sabkha din Sousse, care reprezintă plămânul verde al ariei industriale Sidi Abd Elhamid din nord-estul Tunisiei este necesară pentru îmbunătățirea condițiilor de trai ale populației ce locuiește în cadrul acestui ecosistem. Studiul de față analizează impactul schimbărilor climatice și al activităților antropice asupra comportamentului sezonier și multianual al acestei sabkha cu ajutorul unor serii de imagini satelitare de înaltă rezoluție și unui sondaj de opinie în cadrul locuitorilor zonei. Liniile de țărm din perioada 2003-2019 au fost vectorizat în mediul GIS folosind imagini georeferențiate de pe platforma Google Earth. Ulterior, au fot detectate modificările Land Use Land Cover cu ajutorul software-ului Environment Visualising Imageries. Rezultatele arată că zona construită și cea cultivată au crescut cu 4,3% și respectiv 18,5% în partea de nord și de est a ariei studiate. Mai mult, schimbările climatice din timpul anotimpurilor au dus și la modificări în ocuparea solurilor, de unde rezultă importanța stabilirii unor strategii care să conserve acest ecosistem fragil. Dezvoltarea unui parc urban în jurul sabkha va îmbunătăți condițiile de trai ale populației locale, contribuind totodată la stoparea degradării sabkha.

Cuvinte-cheie: *zonă umedă urbană, modificări climatice, Land Use Land Cover, bunăstare*

Introduction

Wetlands are vital for the survival of humanity. They are among the most productive environments on the planet because they provide the water and productivity on which countless species of plants and animals depend for their survival (Lavoie et al., 2016). Wetlands are of serious significance in hydrological and ecological processes, as one of the world's most productive natural ecosystems. While they have many meanings in the literature, they will be defined for at least a part of the year as areas filled or soaked with water (Kaplan and Avdan, 2018). In this context, Orimoloye et al. (2018) underline that wetlands play a vital role in fostering the ecological diversity of different species. As an example, water birds, fish, amphibians, reptiles, and plant species ensure roosting, spawning, and feeding environments, particularly under severe weather conditions. Therefore, wetlands are an important wildlife breeding and feeding area. They create shelters and protection for aquatic creatures. In addition, they have significant aesthetic, educational, cultural, and spiritual values and provide invaluable opportunities for recreation and tourism (Millennium Ecosystem Assessment, 2005).

According to the Ramsar Convention report (2009), about 64% of the world's wetlands have disappeared since 1900 and it is recognized that the rate of loss of wetlands varies significantly from one nation to another. According to Niu et al. (2012), China has lost 33% in just 30 years from 1978 to 2008. In Tunisia, the total area of wetlands is roughly 1,250,200 ha and they are classified as 64 wadis, 62 Sabkhas, 37 ponds, 14 inland marshes, 4 coastal marshes, 16 chotts, 15 lakes, 5 natural springs and 3 peatlands (Convention on wetlands 2016). However, during the second half of the 20th century these ecosystems continued to decline and are more threatened (Chaabane et al, 2021; Hettiarachchi et.al., 2014). Recently, Abalo et al. (2021) have argued that climate change and anthropogenic pressures affect land resources, especially wetlands. From example, urbanization is one of the leading causes of species loss. It can decrease native species diversity directly by eliminating habitat and indirectly by increasing fragmentation and isolating natural habitat (McCauley et al. 2013). The negative impact of climate change can be deduced in hydrological regimes (Erwin, 2009) and on productivity of wetlands.

A lot of research around the world has been done to study and assess wetlands. From example, Li et al. (2012) have employed in their study an evaluation support system to accommodate the prevalent scenario structures of the Liaohe River Delta wetlands. Remote sensing was used to classify wetlands in central North Dakota (Rover et al., 2011) and Geographic Information System (GIS) was applied to analyze the land cover spatial dynamics of the wetlands located in Dakar (Aimée et al., 2018). Recently, Abalo et al. (2021) have calculated the Normalized Difference Vegetation Index and used Google Earth images to evaluate the land use of wetlands in Togo, particularly in the Ogou basin and have practice the «LECOS» extension of the Quantum GIS software to calculate landscape fragmentation.

Increasingly, remote sensing has has been used to generate landscape maps, information on land cover change, and tracking ecosystem status over broad scales and long-term observation (Lu et al., 2004). Therefore, a variety of research studies demonstrated the usefulness of GIS and remote sensing technology for mapping and monitoring wetlands (Adam et al., 2010; Wu et al., 2018). Recently, images from optical satellites such as Landsat are used to map the surface of Balikdami wetland, located in the central Anatolian part in Turkey (Kaplan and Avdan, 2018) at small and large-scale land cover change detection using bi-temporal and multi-temporal data (Djidel et al., 2013; Yan et al., 2019 and Liu et al., 2020). In Tunisia, Bel Fekih Bousemma et al. (2020) have used the radiometric indexes to assess vegetation, water, and salinity changes of Hergla wetland between 2007 and 2017. The spatial and temporal variation of radiometric indexes was helpful to understand the behavior of wetlands.

The objectives of this study are (i) to analyze the current state of the Sabkha of Sousse with the support of a survey, (ii) to map the spatio-temporal dynamic of the wetland between 2008 and 2019 on both global and local scales using Landsat and GE Time Series Images, iii) to analyze changes according to climate change and anthropic actions and iv) to propose the management of an urban park within the study area.

Materials and Methods

Study area

The Sabkha of Sousse is situated in the Tunisian Sahel, particularly in the south of Sousse city. It covers an area of 43 hectares and it is limited to the north by the deviation of the GP1 road; to the east by the olive groves and the district of Sidi Abd Elhamid; to the south by the railway and Zaouiet Sousse; and to the west by a wastewater treatment plant as well as the National Sanitation Office (ONAS) district (Fig. 1). The study area (35°47'31.6"N 10°38'46.1"E) belongs to the semi-arid bioclimatic stage marked by irregular rainfall. It is fed mainly by rainwater. The fauna is little abundant, because it is almost dry during the dry season. This Sabkha has been recognized and classified as a sensitive wetland by the Ministry of Agriculture since 1996. However, it continues to serve as a real anarchic dumping ground for various types of waste, to give the surrounding landscape a degraded image. In addition, this area is also used to discharge untreated wastewater from the ONAS, which manages a nearby sewage treatment plant.

According to Gammar and Boujarra (1993), soil types are largely dependent on the topographic and morphological position of the grounds and the study area has a sandy texture and therefore correspond to light soils on the hills and plateaus where they bury crusts and quaternary calcareous crusts of quite variable facies (SDARECO, 2011). On the upper parts of these hills, where an ablation dynamic prevails, whether by water erosion or wind deflation, the thickness of these soils is significantly reduced. They have decreased in this way, and little rendzine-type calcareous soil evolution has occurred. It is characterized by a stony pavement reminiscent of the landscape of regs or hamadas. These surfaces are generally arranged in impluviums called locally ≪ meskat ≫ which collect rainwater and drain them to the plots located below (≪ menkaa ≫) through a network of ≪ tabias ≫ (Elouardani et al, 2020).

Sousse city is characterized by the predominance of the topographic flatness, so as to expand the range of floodable perimeters following especially the difficulties of drainage of runoff and their evacuation to the endoreic basins or to the sea. Moreover, two main rivers control the hydrology of Sousse: Oued El Hammam and Oued Hamdoun. These exoreic wadis are essentially characterized by the smallness of their catchment areas and the weakness of their slope (respectively 2 per thousand, 6.0; 8.1 and 2.225) (Sahtout, 2015). The hydrographic network is divided from north to south between seven watersheds. These are basins constituted around the Sebkha Assa Ejjriba, El Kalbyya, Sidi El Hani, Sidi Khalifa, Oued Laya, El Hammam, and Oued Hamdoun. These last ones constitute micro-catchment areas because of their limited surface and the size of the small oueds that drain them. The few oueds of Sousse, such as Laya, Hamdoun, or Kharroub, are temporary or even completely dried up most of the time, thus preventing any development of these waterways by collectors (Ben Salem et al, 2021).

Fig. 1: Localization map of the study area and its surroundings (@Google Earth, 2020)

Methodology

As a first step, a physical analysis was carried to display the soil, vegetation, DEM, hydrographic network and main climatic parameters of the study area (so poor with only these two and only with simply variation, to reflecting climatic changes).

As a second step, a survey about citizens opinion regarding the perception of inhabitants on the Sabkha of Sousse wetland is done by studying the identity, the services, and the state of the wetland. Then, the land use changes were extracted at global and local scales corresponding to ecological, social, and urban transformation between 2008 and 2019.

Finally, the use of wetland mapping conversion and habitat distribution (spatial and temporal) lets us to understand the land changes of the wetland and its surroundings. However, for an improved well-being of the population in this region, a conception of an urban park in the Sabkha will be proposed using AutoCAD software.

Physical analysis

The physical analysis is based on the description of physical components of the study area.

Climate data are downloaded from the NASA open access (https://power.larc.nasa.gov/data-access-viewer), soil and hydrographic resources are collected from the GIS database.

Figure 2 shows that the average monthly rainfall recorded between 2003 and 2019 is highly variable from month to month. October is the rainiest month, while July is the driest. Nevertheless, we note that the winter rainy events are more important these last three years exceeding the average. Between 2003 and 2019, the rainiest year is 2003 with an average annual rainfall of 606.45 mm.

Figure 3 shows that the monthly temperature is almost constant during this period, some slight variations are recorded mainly in winter and marked by increases of 1° C.

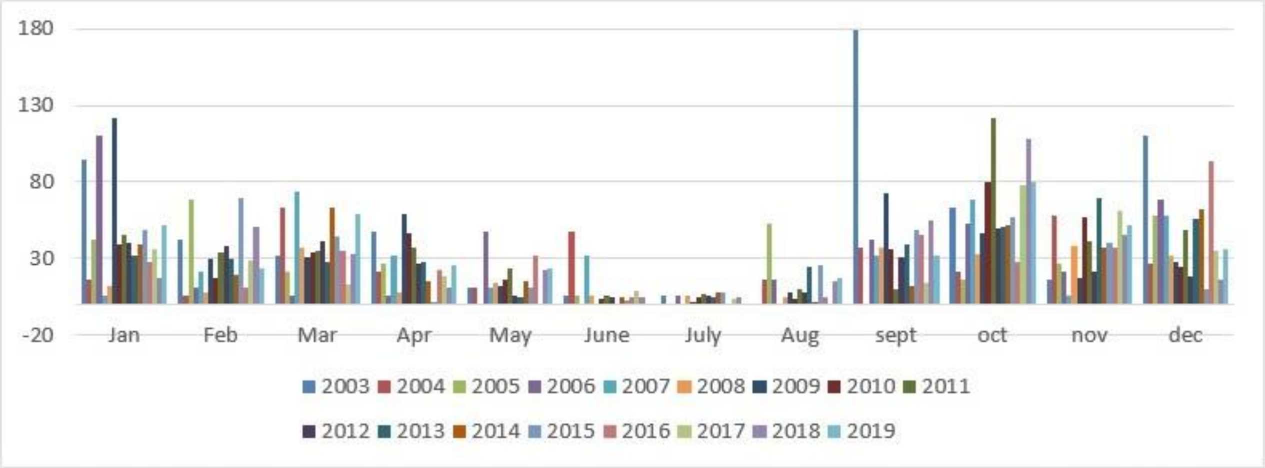


Fig. 2: Variation of the monthly rainfall average in mm per day of Sousse region between 2003 and 2019 (https://power.larc.nasa.gov/data-access-viewer/)

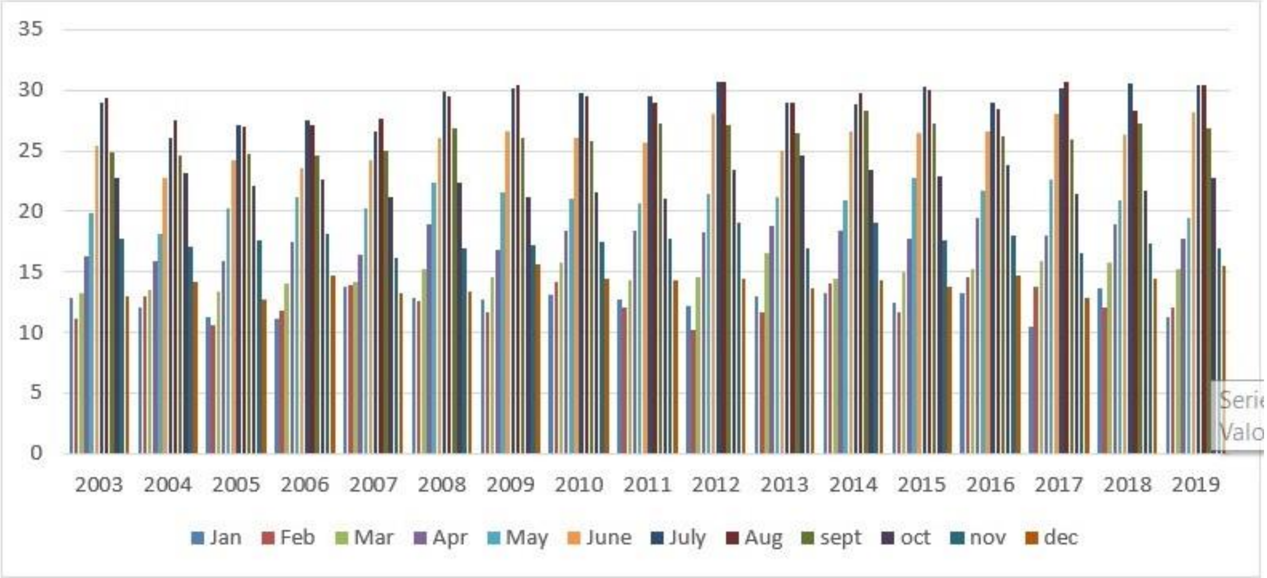


Fig. 3: Variation of the monthly temperature average of Sousse region in ° C between 2003 and 2019 (https://power.larc.nasa.gov/data-access-viewer/)

Questionnaire regarding the citizens opinion on Sabkha of Sousse

The data collection for anthropogenic and social analysis was based on a structured survey of interviewers from different categories (adults, adolescents, housewives, workers, farmers etc.).

It is composed of two sections: i) a social description interested in personal information of the respondents: age, family situation, intellectual level, and profession; and ii) a second section which includes questions that affect identity, service, and state of the Sabkha, its usefulness and the evaluation of its condition.

Data and description of remarkable changes cited by locals are considered. A total of 16 questions were asked to 60 residents and the responses from the interviewers and the key informant interviews were recorded by hand on the notebook and the results were processed in Excel. The survey is a semi-directed one, including qualitative and quantitative information.

Land Use Land Cover study

Given the important role of wetlands in Sousse, Land Use Land Cover (LULC) changes occurring in the uplands, understanding, and assessing wetland conditions requires high resolution data, the remotely sensed data currently available for this region are limited.

In this case, a spatiotemporal analysis at two different scales; global and local was made. Thus, a processing of a time series by the remote sensing tool as well as GE clips were used for a larger scale.

For the global scale, two high resolution Landsat satellite images were downloaded from the USGS platform (https://earthexplorer.usgs.gov/), with a spatial resolution of 30 m, namely Landsat 5TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) dating from 23/08/2008 and 06/03/2019 respectively (Table 1).

Table 1: Characteristics of the Landsat scenes used

	Landsat 5	Landsat 8
Acquisition date	23/08/2008	06/03/2019
Altitude	705 Km	705 Km
Duration of a revolution	99 minutes	99 minutes
Time resolution	16 daysTM	16 daysOLI
Sensors	30*30 m	30*30m
Spatial resolution Mown to	185 Km	
the groundNb of bands	7	10+1P

This kind of images has the advantage of being freely available and widely utilized in wetland mapping (Abalo et al. 2021). Atmospheric and radiometric corrections were done using the ENvironment Visualizing Images 5.1. The reflectance calibration consists of deriving the reflectance value from the Digital Number and calculating the top of atmosphere reflectance attention (Azabdaftari and Sunar, 2016). Ground verification data was obtained from sample locations using the Garmin 6S Map to enhance the consistency of the thematic resource data prepared (Singh et al. 2020; Ogato et al. 2021).

The Table 2 shows the six LULC classes determined and used for the supervised classification of Landsat images and the description of each class. Then, a maximum likelihood (MKL) classification system was applied to both images. This method aims to facilitate the development of land cover classes and is more rigorous in the classification process (Gutierrez and Johnson 2010). It is based on the probability that a pixel belongs to a particular class. However, it needs a long time of computation, it relies heavily on a normal distribution of the data in each input band and tends to over classify signatures with relatively large values in the covariance matrix (Rawat and Kumar, 2015).

That's why, Kappa method was used to assess the mapping accuracy (Bonn and Rochon, 1992), and when confusion existed, high resolution maps of GE and its online ground imagery were regularly consulted. Inputs are the original satellite or aerial image, which must be processed to calibrate the radiance reaching the sensor and to geometrically correct the image to fit a selected geographic map projection. Then, the ground truth information from the GIS is added to this mapped image. The result is an image of the land cover from the land cover and classification system. At this point new features are added to the land cover data base and the GIS data base.

Table 2: Description of the LULC classes determined for the supervised classification

LULC	Description	Picture
Urban	Areas occupied by urban residential houses, buildings, and industrial uses	
Wet areas	The wetland of Sousse	
Olive groves	Plot Land occupied by olivetrees	
Grassland	Land dominated mainly by grasses and forbs	
Uncultivated soil	Uncultivated plot with natural vegetation	
Agricultural mosaic	Land with bushes and shrubs, small trees scattered and mixed with grasses	

Six GE images were employed, at the local scale, to detect changes on the wetland and specially to identify the major land use land cover of the area and to draw the shorelines of the Sabkha. Years were chosen between 2009 and 2019 according to the seasonal variations and the visibility of the images.

Results

Characterization of the state of the Sabkha of Sousse

The wetland of Sousse is formed by a depression in which the runoff from the surrounding heights collects. The drop in the site is very low. The longitudinal plot represents an altitude variation between 6 m and 12 m. While the vertical plot indicates a variation between 11 m and 8 m (Fig. 4).

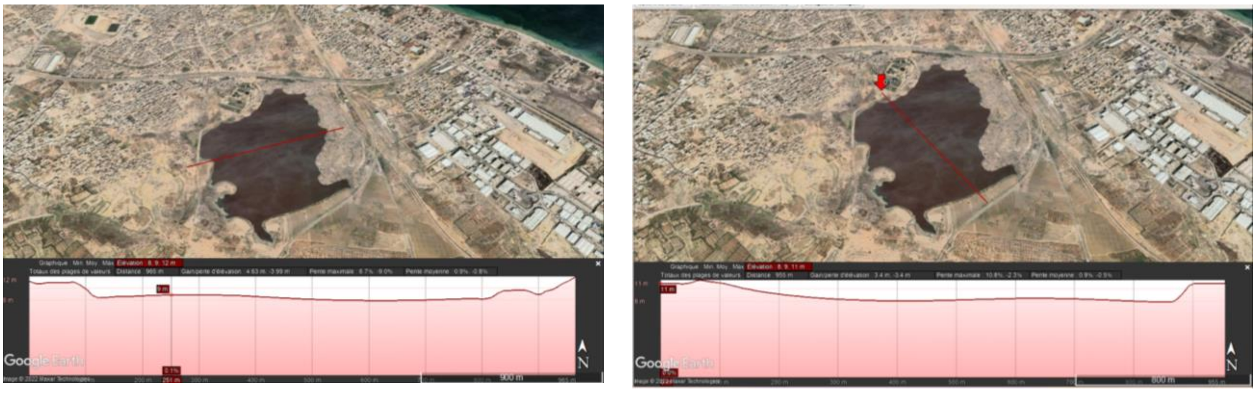


Fig. 4: Variation of the study area elevation (at left Longitudinal, at right Vertical) (@Google Earth, 2020)

Halophyte vegetation is present on the banks of the study area and invasive plants were observed all around the Sabkha. The species present are annuals and halophytes of the Chenopodiaceae family and grow in moist, sandy or clayey soils with high salinity such us *Halumioneport lacoides*, *Suaedamaritina*, *Arthrocnemumm acrostachyum*, *Salicornia arabica*, *Holocnemum strobilaceum* and *Atriplex inflata*.

To analyze the current state of the site, an assessment of the strengths and constraints of Sabkha Sousse had been made.

Constraints

(1) The soils are very salty and have undergone a natural modification by urban waste and landfills, so the species chosen to be planted must be tolerant to salts and lateral rooting. (2) The water supply of the Sabkha is very limited since the rivers are very small and the groundwater is polluted, because the treatment plant implemented on the northwest side rejects the wastewater on the wetland, so the water has a poor quality. (3) The natural flora of the study area is marked by its necrotic state. (4) The fauna is in disappearance; ecological niches are very rare as well as most of the characteristic species of the environment have disappeared. (5) The industries all around the wetland have a negative impact on the environment, the health of the inhabitants as well as the ecological state of the Sabkha. (6) The local population suffers from the problem of unemployment; we remarked a lack of craft activities. (7) There is no security, and the adjacent popular neighborhoods are dangerous. (8) The banks of the wetland are filled with household and industrial refuse.

Strengths

(1) The location of the study area is strategic. (2) Atriplex inflata takes top rank among the local species found in the study area. (3) There are aquatic insects, amphibians, and some migratory birds. (4) Agriculture is developed all around the wetland (crops, olive groves) with the absence of any use of pesticides and insecticides. (5) The wetland offers distinctive character and panoramic views over agricultural land and the urban center of Sousse.

In this situation, it is necessary to take advantage of the ecosystem services provided by the Sabkha to ensure its integration into its environment for its sustainability. Then, managers of the wastewater treatment plant must also find a radical solution to no longer disturb and pollute the Sabkha further. The rivers must be protected and the cultivated areas which delimits the wetland should not be neglected to manage and protect this area.

Land Use Land Cover changes

Global scale

Figure 5 shows that in 2008, the built-up areas are almost located near the costal side, which represented the urban core of the city, which occupied only 9.35 %. Whereas in 2019, some patches are detected in the middle- east (13.62 %). The olive fields are situated in the middle eastern and the southeastern part, with 43.74 % in 2008 and 31.55 % in 2019. The wet areas in this city are formed entirely by Sousse Sabkha, which was marked by its instability between 2008 and 2019, changed from 0.12 % to 0.10 %. Moreover, in 2008, the agriculture mosaics sited were mainly in the northeast with 11.69%, and in 2019 new fields are detected in the middle-west (30.22 %). The occupations of uncultivated soil evolved from 7.04% to 11.80% and this especially around the Sabkha. The grasslands scattered throughout the region, decreasing from 28.06 % to 12.71 %.

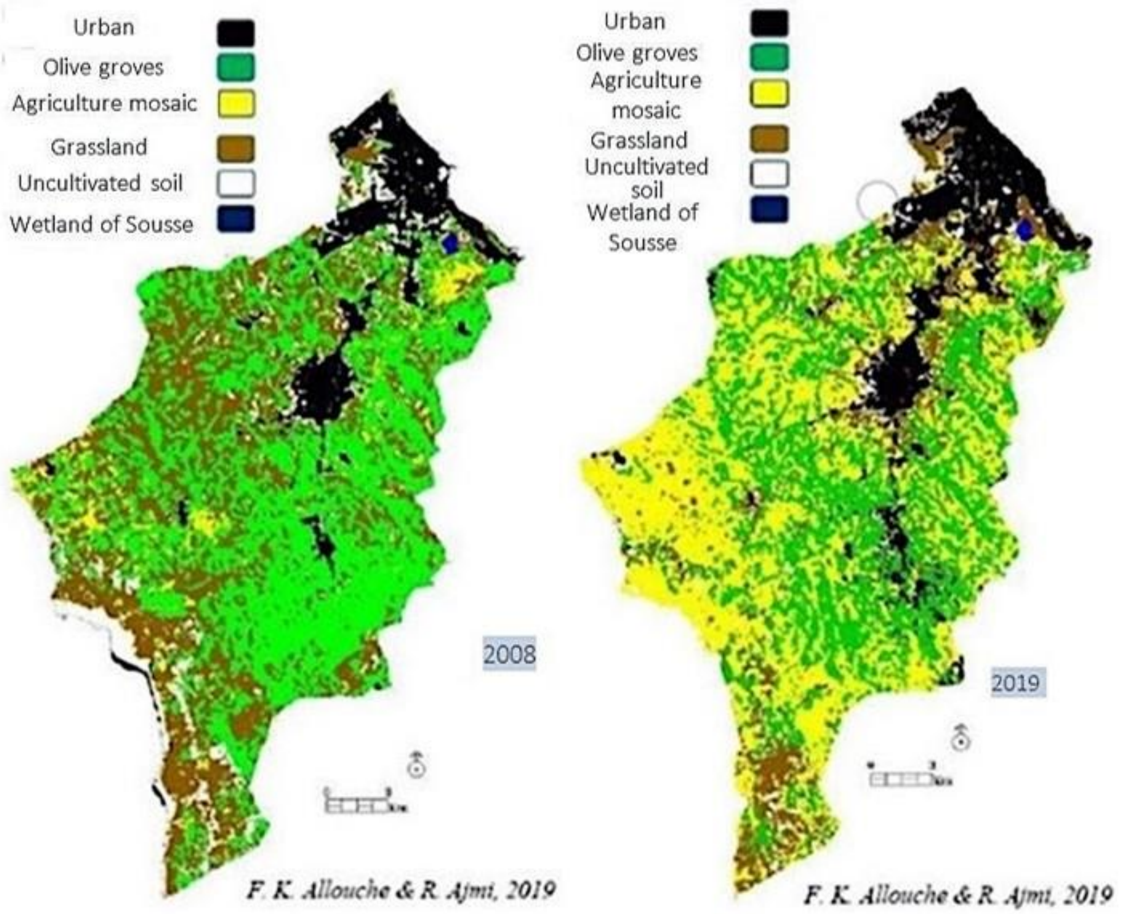


Fig. 5: LULC maps of Sousse region (at left in 2008, at right in 2019)

Local scale

Zooming in to the level of the Sabkha of Sousse, Figure 6 shows the increase in built-up areas on the west side with a reduction in the areas of olive groves.

It is due to the importance of the development of urbanization and its corresponding facilities (housing estates, roads, industrial areas, parking, landfills, etc.) mainly on the southwestern side of the Sabkha which has been achieved to the detriment of the wetland. It is thus threatened by compartmentalization and pollution. Hence, the importance of limiting the phenomenon of urban sprawl. Nevertheless, climate change will directly alter ecosystem services, for example, by causing changes in the productivity and growing zones of cultivated and non-cultivated vegetation and indirectly, by leading to sea level rise, which threatens the Sabkha and other vegetation that protect the shorelines.

Fig. 6: LULC changes in the Sabkha of Sousse at the northwest side (at left in September 2009, at right in December 2018, @Google Earth)

Figure 7 reveals that in August 2009, the Sabkha is almost dry while in January 2014, it is engorged with water. This is due to climate change during these periods, in fact in August 2009 the precipitation is equal to 8.10 mm and the average temperature are 30.4° C while in January 2014 the precipitation is equal to 38.7 mm and the average temperature is at 13.3° C (https://www.learngeom.com).

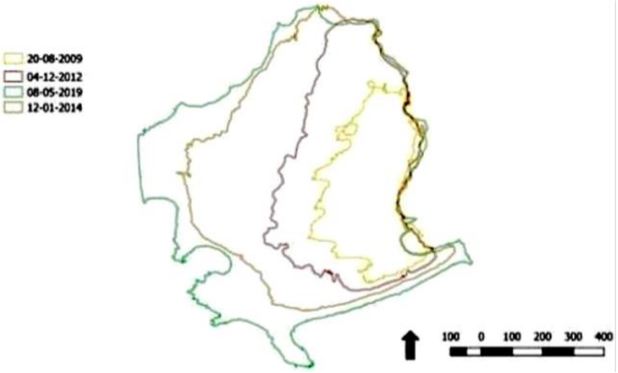


Fig. 7: Spatial-temporal variation of Sabkha Sousse shorelines between 2009 and 2019

Figure 8 illustrates that the area of the wetland changes with the season, in fact it has an area of 143 m² during the summer season of 2009 against 527 m² during the winter season of 2014. Therefore, climate elements as background for wetland change, which are mainly revealed through temperature and precipitation, influence the growth and decline of wetlands. Certainly, increased precipitation expands wetland, which makes a positive correlation between them. In contrast, the temperature effect on wetland is more complex. So, rising temperatures increase evaporation, accelerating loss of water in wetland, thus its area shrinks.

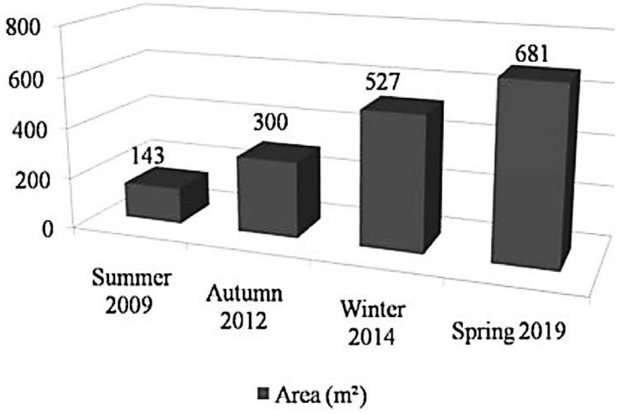


Fig. 8: Seasonal variation in Sabkha Sousse between 2009 and 2019

Impacts of Climate change actions

The Sabkha has been affected by climate change in recent decades with an increasing sensitivity gradient from West to East.

Figure 9 indicates that the Sabkha branch off several streams presented by the main course of Oued Hamdoun, which is directly connected to the sea. Thus, it plays an important role in the Oued Hamdoun watershed, from where it must be preserved from any destruction so that it retains its function of regulating floods and protecting its waterways. The water inlets and outlets of the Sabkha are not well identifiable, indeed the rivers of the Sabkha have been disturbed by the setting of the GP1 belt road on its north side as well as the railway line on the west side. This has disturbed the hydrological system of the Sabkha. Thus, the hydraulic continuity is broken, and the wetland will no longer be supplied with water and may disappear.

Fig. 9: Sousse Sabkha hydrographic network (@ Google earth, 2015)

Figure 10 shows that the lower part of the site on the south side is damaged by storm water runoff so the study field becomes very rough and makes movement very difficult. However, on this side, the rivers feed the Sabkha.

The increase in seasonal contrasts in recent years marked mainly by summer rain events and rising autumnal temperatures will have a negative impact on the biotopes of the Sabkha which will have an annual hydrological cycle marked by strong seasonal variations modeled on the rainfall rate (Fig. 11).

Fig. 10: Traces of streams on the southwest side of the Sousse Sabkha after the rain events recorded on 15/10/2019

In addition, aquatic populations will respond to water and thermal stresses through adaptive changes in biology, population dynamics and distribution, and in the taxonomic composition and richness of communities.

This climatic irregularity marked by rainy events, rising temperatures, intense evaporation (partial or total drying out) will strongly contribute to the impoverishment of aquatic fauna, the scarcity or disappearance of certain vulnerable species.

This will lead to a loss of specific biological diversity, a decrease in productivity and a disruption of the distribution of flora and habitats for fauna.

Fig. 11: Google Earth clips from the Sabkha of Sousse at west side (at left in August 2009, at right in May 2018)

The perception of inhabitants on the Sabkha of Sousse

Figure 12a illustrates that the entire population surveyed does not benefit from the Sabkha in any way and does not use it for irrigation or other purpose. 44% of the surveyed population considers the Sabkha as a space which has nothing to do with it and which does not represent anything to it, the age range of most of this category is between 25 and 35 years.

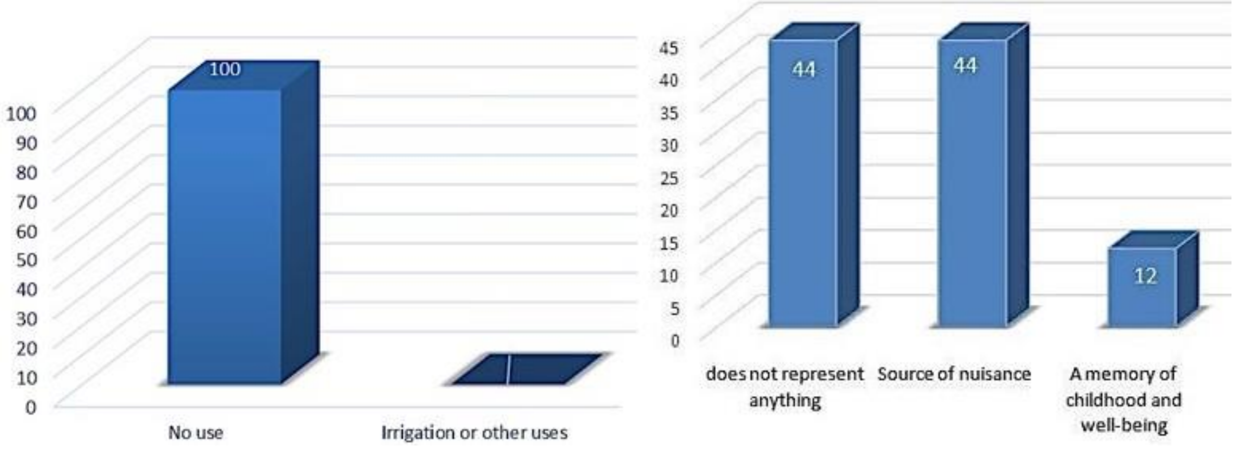


Fig. 12: Uses of the Sabkha (a); residents' perceptions of the Sabkha (b)

The same proportion (44%) is accorded for those who consider the Sabkha as a source of nuisance and pollution and only 12 % of the interviewers have a memory of childhood and recreational role of this wetland (Fig. 12b).

Figure 13a shows that 72% of the interviewed inhabitants have noticed that the condition of the Sabkha changes with the seasons and according to Figure 13b, 72% of the inhabitants surveyed claimed that during the summer the state of Sabkha is worse than in the winter. The results of the survey carried out among farmers showed that according to their opinion, the urban extension and the climate change caused the instability of the current state of the Sabkha, a decrease in olive groves in the surroundings and deterioration of the life quality in the outlying districts.

The analysis showed the increase in cultivated areas around the wetland and the figures show this increase between 2009 and 2018 which contributed to the evolution of agricultural needs, by stimulating pumping for irrigation. The inflow of water from the groundwater to surface aquatic systems is therefore likely to decrease significantly, modifying the ecological functioning of wet-lands, interfaces between groundwater and surface water. So, we must put in place strategies to deal with these changes which have negative consequences on the wetland.

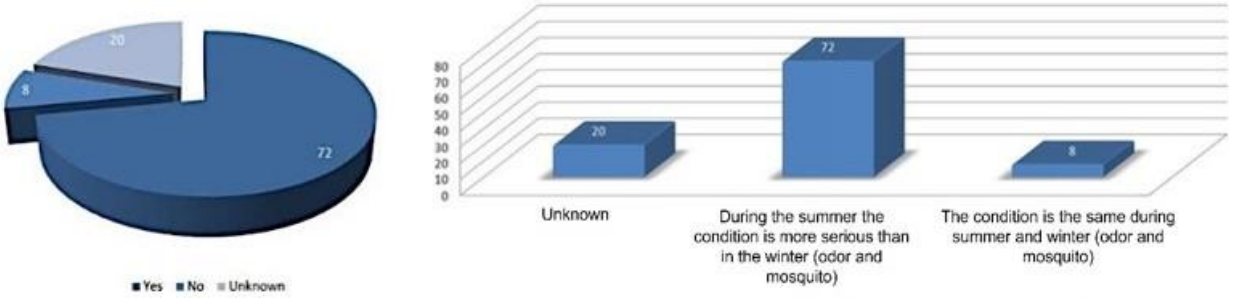


Fig. 13: Change of state of the Sabkha according to the seasons (a); state of Sabkha in the winter and summer (b)

The urban wetland of Sousse as a green lung

The analysis of the state of the Sabkha according to climatic and anthropogenic factors has shown that this ecosystem is threatened by a severe degradation. However, the deterioration of wetlands constitutes a danger, due to the role that these ecosystems play in climate regulation. Indeed, they can store water in the ground or retain it on their surface; reduce the intensity of floods and the damage caused by flooding; the water accumulated during rainy periods or during exceptional weather events can gradually feed groundwater and rivers during dry periods and they mitigate global warming. In general, carbon is sequestered by vegetation, via photosynthesis. In addition, the local population has expressed an interest in the management of this space for their well-being, hence the idea of proposing a landscaping management to reduce the impact of the various factors and improve the environment for city dwellers.

The Sabkha represents a very fragile ecosystem, which has become more and more degraded because of the mismanagement of the actors of the territory and the weakness of the means to fill its shortcomings. Nevertheless, this ecosystem still represents an ecological potential which must be developed to restore and preserve the environmental quality of this area and restore the natural functions of the Sabkha. In this context, the restoration of the Sabkha river and the development of its banks into an urban park has been adopted as a development strategy. The aim of this project is to conserve this vulnerable ecosystem and to develop recreational functions in this landscape to the residents. The Park has an area of about 42 ha. The concept is based on the "Integration". The idea derived from the principle of incorporating this "sensitive" area into its urban, social, hydrographic, and natural environment to improve human well-being and save natural resources by using ecological and social scenarios.

For those reasons, seven action programs are proposed. (1) The discovery trail is a path on planking which is composed of piles assembled by means of crossbeams. It is equipped with benches on both sides and with information panels. (2) Prairies are created to reconstitute quality habitats for fauna and flora. *Carexelata Aurea* is used as a ground cover and *Phragmites australis* will be planted as oxygenating properties for the water in the filtration zone, to fix the banks and the zones subject to erosion. (3) Wooded areas are planted mainly with eucalyptus, a species that shuns insects. They will be equipped with wooden kiosks, useful for birdwatching, in- formation and awareness panels. (4) Educational plots of minimal and composed of containers, double-bottomed bins, shaded by eucalyptus trees are designed. (5) Playground areas are equipped with wooden constructions and benches where parents can rest next to their children. (6) Observation stations, footbridges and platforms are developed to allow the visitor to discover discreetly the fauna and flora species and finally (7) two entries are arranged, a main one and a secondary one (Fig. 14).

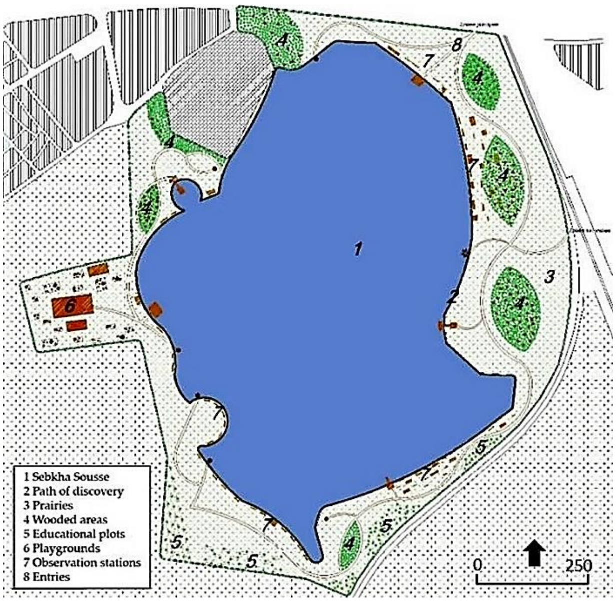


Fig. 14: Master plan of the wetland urban park, Sousse

Discussion

Wetlands are one of the most valuable natural resources in the world. They play major ecological functions, absorbing toxic chemicals and pollutants, storing natural carbon, recycling nutrients, while also contributing to groundwater recharge in arid and semi-arid regions (Chenchouni et al. 2015). While the objective of our study is to analyze the impact of climate change and human activities on the seasonal and pluriannual behavior of this Sabkha by using a multitemporal Landsat satellite imageries and other imageries obtained from GE platform, the results have clearly shown the negative impacts of urban sprawl around the Sabkha of Sousse. As has been extensively debated in previous research, urbanization is a principal cause for land-use change (Salvati et al. 2018; Dadashpoor et al. 2019; Tang et al. 2020). The results of the global and local scale analysis convey that the built-up area have increased between 2008 and 2019. Urbanization is a major cause of destruction in coastal wet-lands, and it has a serious effect on their structure and function (Lee et al. 2006; Li et al. 2010). Moreover, the decrease in water volume has far reaching environmental effects for and beyond the area. This phenomenon was demonstrated by Ogato et al. (2021), who suggested some possible causes for this decline, pointing to both human and natural influences. Therefore, climate fluctuations in various areas would have differing impacts with respect to wetlands (Niu et al. 2012). In Tunisia, Bel Fekih Bousemma et al. (2020) have studied the LULC of Halq El Mingel. So, the total wetland area Over the past ten years, more than 4% of the natural wetland has been destroyed, reducing the overall area of wetlands. and this variation is probably linked to climatic effects.

In fact, the Spatial-temporal variation of Sabkha Sousse shorelines is an urbanization impact on runoff and discharge. Ecosystem resources could be lost because of these shifts in ecosystem systems, which will have a detrimental effect on biodiversity, culture, and the environment (Wiederkehr et al. 2020).

In our study, an exceptionally anarchic extension on the banks of the Sabkha is detected, associated with a spontaneous nibbling of the agricultural belt and a deterioration of the quality of life in the disadvantaged peripheries. This process was also identified in the study prepared by Chouari (2013) on the Sijoumi wetland and many other Mediterranean wetlands. This requires the development of a management and sustainable strategy of these fragile areas to preserve them. Thus, conservation and regeneration programs and policies can be integrated with economic local development and hunger reduction practices and initiatives (Yohannes et al. 2020). According to Bel Fekih Boussema et al. (2020), wetlands are important not only for their ecological but also their social and economic effects. Their decline can generate critical consequences such as increasing costs for water quality treatment, improved infrastructure for regulation of floods and programs for elimination of invasive species.

Conclusion

The urban wetland of Sousse represents the green lung of the industrial area of Sidi Abd Elhamid and the only virgin space where the inhabitants can take refuge. It is a large place that gives the impression of freedom in the middle of nature, offering panoramic views of the different types of landscapes that surround it. In fact, the Sabkha regulates the flow of water in the river basin, preventing flooding by halting, collecting, and eventually returning water. It is therefore a true hydrological reservoir since it stores water at some periods before releasing it to another. The application of an integrated methodological approach made it possible to characterize and evaluate the state of this ecosystem. However, the use of remote sensing and GIS tools has helped to detect its spatiotemporal and anthropogenic dynamics according to the results of surveys carried out among the local population. In addition, this study made it possible to prove once again the effectiveness of such methods and tools at regional and local scale. Thus, development proposals for the banks of the Sabkha to minimize pollution, to reintegrate the agricultural practice by the development of educational plots and to integrate discovery and entertainment activities by the development of discovery trails and playgrounds will play an essential role in improving the living environment of the population in the face of climate change.

Funding

This research received no external funding.

Acknowledgements

The authors would like to express their appreciation for the municipality of Sousse, Tunisia, for the administrative and technical support.

Author contribution

Conceptualization, Faiza Khebour ALLOUCHE and Rania AJMI; methodology, Faiza Khebour ALLOUCHE and Rania AJMI; formal analysis, Faiza Khebour ALLOUCHE, Rania AJMI and Safa belfekih BOUSSEMA; writing—original draft preparation, Faiza Khebour ALLOUCHE and Rania AJMI; writing—review and editing, Safa belfekih BOUSSEMA and Gheorghe ȘERBAN. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Abalo, M., Badabate, D., Fousseni, F., Kpérkouma, W., & Koffia, A. (2021). Landscape-based analysis of wetlands patterns in the Ogou River basin in Togo (West Africa). *Environmental Challenges*, 2, 100013. https://doi.org/10.1016/j.envc.2020.100013

Adam, E., Mutanga, O., & Rugege, D. (2010). Multispectral and hyperspectral remote sensing for identification and mapping of wetland vegetation: a review. *Wetlands Ecology and Management*, 18, 281–296. https://doi.org/10.1007/s11273-009-9169-z

Aimée, D., Sambou, H., Diop, C., Ntiranyibagira, E., Dacosta, H., & Sambou, B. (2018). Dynamique d'occupation du sol des zones humides urbanisées de Dakar (Sénégal) de 1942 à 2014. *Protection internationale du climat et souveraineté étatique*, 18, 1. https://doi.org/10.4000/vertigo.201

Azabdaftari, A., & Sunar, F. (2016). Soil salinity mapping using multitemporal Landsat data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLI-B7, 3-9. https://doi.org/10.5194/isprs-archives-XLI-B7-3-2016.

Bel Fekih Boussema, S., Khebour Allouche, F., & Chaabane, B. (2020). Tools and Indicators for Integrated Wetland Monitoring Case of Hergla Wetland –Tunisia. *European Academic Research*, 8:6, 3230-3245.

Ben Salem, A., El Amri, A., M'nassri, S., Chokman, K., & Majdoub, R. (2021). Spatio-Temporal Monitoring of the Meskat System Distribution in the Tunisian Sahel Region Using TM Landsat Images. In: Khebour Allouche, F., Negm, A.M. (eds) *Environmental Remote Sensing and GIS in Tunisia. Springer Water. Springer*, Cham. https://doi-org.buadistant.univ-angers.fr/10.1007/978-3-030-63668-5_4

Bonn, J.F., & Rochon, G., UREF. (1992). Précis de télédétection volume 1, Principes et méthodes. Presses de l'Université du Québec, Sillery, Québec.

Boujarra, A., Gammar, A.M. (1993). Contribution à l'étude géomorphologique des niveaux à croûtes dans les environs de Sousse.

Chaabane, B., & Khebour Allouche, F. (2021). A Historical Look at the Spatiotemporal Dynamics of Tunisian Wetlands by Earth Observation. *Chapter book: Environmental Remote Sensing and GIS in Tunisia*, 329–347

Chenchouni, H., Menasria, T., Neffar, S., Chafaa, S., Bradai, L., Chaibi, R., Mekahlia, MN., Bendjoudi, D., & Si Bachir, A. (2015). Spatiotemporal diversity, structure, and trophic guilds of insect assemblages in a semi-arid Sabkha ecosystem. *PeerJ*, 3: e860. https://doi.org/10.7717/peerj.860

Chouari, W. (2013). Problèmes d'environnement liés à l'urbanisation contemporaine dans le système endoreïque d'Essijoumi (Tunisie nord-orientale), *Physio-Géo*, 7:1, 111-138.

Dadashpoor, H., Azizi, P., & Moghadasi, M. (2019). Land use change, urbanization, and change in landscape pattern in a metropolitan area. *Sci. Total Environ*, 655:10, 707-719. https://doi.org/10.1016/j.scitotenv.2018.11.267

Djidel, M., Labar, S., Medjani, F., & Bouafia, I. (2013). Étude des changements écologiques des zones humides en milieux désertiques en utilisant l'imagerie Landsat et le SIG. *International Journal of Environment & Water*, 5,2.

Erwin, K.L. (2009). Wetlands and Global Climate Change: The Role of Wetland Restoration in a Changing World. *Wetlands Ecology and Management*, 17, 71-84. http://dx.doi.org/10.1007/s11273-008-9119-1

Hettiarachchi, M., H. Morrison, T., Wickramsinghe, D., Mapa, R., De Alwis, A., & Mc Alpin, C.A. (2014). The eco- social transformation of urban wetlands: A case study of Colombo, Sri Lanka. *Landcape and Urban Planning*, 132, 55-68. https://doi.org/10.1016/j.landurbplan.2014.08.006

Kaplan, G., & Avdan, U. (2018). Monthly Analysis of Wetlands Dynamics Using Remote Sensing Data.

ISPRS Int. J. Geo-Inf, 7:10, 411. https://doi.org/10.3390/ijgi7100411

Lavoie, R., Deslandes, J., & Proulx, F. (2016). Assessing the ecological value of wetlands using the MACBETH approach in Quebec City. *Journal for Nature Conservation*, 30, 67-75. https://doi.org/10.1016/j.jnc.2016.01.007

Lee, S.Y., Dunn, R.J.K., Young, R.A., Connolly, R.M., Dale, P.E.R., Dehayr, R., Lemckert, C.J., McKinnon, S., Powell, B., Teasdale, P.R., & Welsh, D.T. (2006). Impact of urbanization on coastal wetland structure and function. *Austral Ecology*, 31:2, 149-163. https://doi.org/10.1111/j.1442-9993.2006.01581.x

Li, Y., Zhu, X., Sun, X., & Wang, F., (2010). Landscape effects of environmental impact on bay-area wetlands under rapid urban expansion and development policy: A case study of Lianyungang, *China Landscape and Urban Planning*.94, 3-4, 218-227. https://doi.org/10.1016/j.landurbplan.2009.10.006

Li, X., Liang, C., & Shi, J. (2012). Developing Wetland Restoration Scenarios and Modeling Its Ecological Consequences in the Liaohe River Delta Wetlands, China. *CLEAN – Soil, Air, Water*, 40:10, 1185-1196. https://doi.org/10.1002/clen.201200025

Liu, D., Chena, N., Zhang, X., Wang, C., & Du, W. (2020). Annual large-scale urban land mapping based on Landsat time series in Google Earth Engine and OpenStreetMap data: A case study in the middle Yangtze River basin. *ISPRS Journal of Photogrammetry and Remote Sensing*, 159, 337-351. https://doi.org/10.1016/j.isprsjprs.2019.11.021

Lu, D., Mausel, P., Brondízio, E., & Moran, E. (2004). Change detection techniques, *International Journal of Remote Sensing*, 25:12, 2365-2401. https://doi.org/10.1080/0143116031000139863

Mahdianpari, M., Jafarzadeh, H., Granger, J.E., Mohammadimanesh, F., Brisco, B., Salehi, B., Homayouni, S., & Weng, Q. (2020). A large-scale change monitoring of wetlands using time series Landsat imagery on Google Earth Engine: a case study in Newfoundland. *GIScience & Remote Sensing*, 57:8, 1102-1124. https://doi.org/10.1080/15481603.2020.1846948

McCauley, L.A., Jenkins, D.G. & Quintana-Ascencio, P.F. (2013). Isolated Wetland Loss and Degradation Over Two Decades in an Increasingly Urbanized Landscape. *Wetlands*, 33, 117–127

Millennium Ecosystem Assessment. (2005). Ecosystems and human well- being: wetlands and water, synthesis.World Resources Institute, Washington, DC

Niu, Z., Zhang, H., Wang, X., Yao, W., Zhou, D., Zhao, K., Zhao, H., Li, N., Huang, H., Li, C., Yang, J., Liu, C., Liu, S., Wang, L., Li, Z., Yang, Z., Qiao, F., Zheng, Y., Chen, Y.,Sheng, Y., Gao, X., Zhu, W., Wang, W., Wang, H., Weng, Y., Zhuang, D., Liu, J., Luo, Z., Cheng, X., Guo, Z., & Gong, P. (2012). Mapping wetland changes in China be-tween 1978 and 2008. *Chinese Science Bulletin*, 57, 2813-2823.

Ogato, G.S., Bantider, A., & Geneletti, D. (2021). Spatio-temporal Dynamics, Drivers, Effects and Environmental Implications of Land use/land Cover Changes in Ambo Town and Its Watershed, West Shoa Zone, Oromia Regional State, Ethiopia. *Environmental Systems Research*. https://doi.org/10.21203/rs.3.rs-106883/v1

Ogato, S.G., Bantider, A., & Geneletti, D. (2021). Dynamics of land use and land cover changes in Huluka watershed of Oromia Regional State, Ethiopia. *Environmental Systems Research*, 10,10. https://doi.org/10.1186/s40068-021-00218-4

Orimoloye I., Kalumba A., Mazinyo S., & Nel, W. (2018). Geospatial analysis of wetland dynamics: Wetland depletion and biodiversity conservation of Isimangaliso Wetland, South Africa. *Journal of King Saud University – Science*.

Ramsar Convention. (2009). Wetlands: a global disappearing act. Available at https://goo.gl/GCBTT9 (accessed on 08/02/2021).

Ramsar convention. (2016). An Introduction to the Convention on Wetlands (previously The Ramsar Convention Manual), Ramsar Convention Secretariat, Gland, Switzerland.

Rawat, J.S., & Kumar, M. (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*. Volume 18, Issue 1, Pages 77-84. ISSN 1110-9823, https://doi.org/10.1016/j.ejrs.2015.02.002.

Sahtout, N., El Amri, A., Fourati, M., & Majdoub, R. (2015). Les facteurs de la pauvreté hydrique du Grand Sousse : Un déséquilibre en eau agricole en perspective ?. *European Journal of Scientific Research* 136(3):320-334.

Salvati, L., Zambon, I., Chelli, F.M., & Serra, P. (2018). Do spatial patterns of urbanization and land consumption reflect different socioeconomic contexts in Europe. *Sci. Total Environ.*, 625, 722-730. https://doi.org/10.1016/j.scitotenv.2017.12.341

SDARECO. (2011). Schema Directeur D'Aménagement De La Region Economique Du Nord-Est Atlas Cartographique.http://www.mehat.gov.tn/fileadm in/user_upload/Amenagement_Territoire/SDAREco/AtlasSDARECOnordEstFR.pdf

Singh, S., Bhardwaj, A., & Vermaet, V.K. (2020). Remote sensing and GIS based analysis of temporal land use/land cover and water quality changes in Harike wetland ecosystem, Punjab. India. *J Environ Manage*, 262, 110355. https://doi.org/10.1016/j.jenvman.2020.110355

Tang, J., Li, Y., Cui, S., Xu, L., Ding, S., & Nie, W. (2020). Linking land-use change, landscape patterns, and ecosystem services in a coastal watershed of southeastern China. *Global Ecology and Conservation*, 23, e01177. https://doi.org/10.1016/j.gecco.2020.e01177.

Wiederkehra, F., L.Wilkinson, C., Zeng, Y., C.J.Yeo, D., M.Ewers, R., & J.O'Gormand, E. (2020). Urbanisation affects ecosystem functioning more than structure in tropical streams. *Biological Conservation*, 249, 108634. https://doi.org/10.1016/j.biocon.2020.108634

Wu, Q. (2018). GIS and Remote Sensing Applications in Wetland Mapping and Monitoring. In: Huang, B. (Ed.), *Comprehensive Geographic Information Systems*, 2, 140–157. http://dx.doi.org/10.1016/B978-0-12-409548-9.10460-9

Yan, J., Wang, L., Song, W., Chen Xiaodao, Y., & Ze Deng, C. (2019). A time-series classification approach based on change detection for rapid land cover mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, 158, 249-262. https://doi.org/10.1016/j.isprsjprs.2019.10.003

Yohannes, H., Soromessa, T., Argaw, M., & Dewan, A. (2020). Changes in landscape composition and configuration in the Beressa watershed, Blue Nile basin of Ethiopian Highlands: historical and future exploration, https://doi.org/10.1016/j.heliyon.2020.e04859

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **186**-**200**
http://dx.doi.org/**10.5775/fg.2022.045.d**

Ecosystem services versus wellbeing – implications for sustainable tourism: the host perspective

Anna DŁUŻEWSKA[1], Zbigniew PODGÓRSKI[2], Andrea GIAMPICCOLI[3]

[1] Department of Earth Sciences and Spatial Management, Maria Curie Sklodowska University, Poland; Honorary Research Associate, Faculty of Management Sciences, Durban University of Technology, South Africa
[2] Faculty of Geographical Sciences, Kazimierz Wielki University of Bydgoszcz, Poland
[3] Department of Hospitality and Tourism; Durban University of Technology, South Africa
* *Corresponding author*: dluzewska.a@gmail.com

Received on 23-02-2022, reviewed on 05-06-2022, accepted on 10-06-2022

Abstract

This paper aims to compile red flags appearing at the interface of hosts' wellbeing, ecosystem services (ES) and tourism, which have already been described in the literature. We focus on host communities in developing countries, as poor and disadvantaged people much more often depend directly on ES. We start with a description of the concepts ES and wellbeing. The second section describes prominent gaps and challenges in the ES–wellbeing interface, with special focus on those that can be relevant to tourism (such as the establishment of protected areas, the concept of paying for ES, poverty reduction, endowments vs entitlements). The third section is devoted to a discussion of the identified gaps and challenges. The last section contains conclusions and implications. These recommendations are global and fairly general indications that should be considered at the interface between ES, tourism and wellbeing policies, whatever the context.

Keywords: *ecosystem services, cultural ecosystem services, wellbeing, sustainable tourism, community wellbeing, paying for ecosystem services*

Rezumat. Serviciile ecosistemice versus bunăstare – implicații pentru turism durabil din perspectiva comunităților gazdă

Lucrarea își propune să întocmească un inventar al semnalelor de alarmă la interfața dintre bunăstarea comunităților gazdă, a serviciilor ecosistemice (SE) și turismului, care au fost deja semnalate în literatura de specialitate. Ne-am axat pe comunitățile gazdă din statele în curs de dezvoltare, întrucat persoanele sărace și dezavantajat depind într-o măsură mult mai mare de SE. Începem printr-o descriere a conceptelor de SE și bunăstare; cea e a doua secțiune prezintă principalele discrepanțe și provocări în relația SE-bunăstare, cu un accent special pe elementele relevante pentru turism (ex. înființarea unor arii protejate, conceptul de a plăti pentru SE, reducerea sărăciei, înzestrare vs drepturi). A treia parte cuprinde discuțiile referitoare la discrepanțele și provocările identificate, în timp ce ultima parte este dedicată concluziilor si implicațiilor acestui studiu. Acestea sunt recomandări globale și indicii generale care ar trebui considerate în politicile privind relația dintre SE, turism și bunăstare, indiferent de context.

Cuvinte-cheie: *servicii ecosistemice, servicii culturale, bunăstare, turism durabil, bunăstarea comunității, plata pentru serviciile ecosistemului*

Introduction

The guidelines for sustainable development assume decent behaviour by all actors. Equilibrium between the economic and environmental pillars, and retaining the "goods" for future generations, in general are not subject to formal criticism by decision makers or most stakeholders. In practice, these notions remain at the stage of rhetorical declarations, often because of actual conflicts between actors, the discrepancy of their interests or lack of strategic thinking. The difficulty of implementing sustainable development goals with reference to the environment was the main reason for creating the term "ecosystem services" (ES). This economic valuation allowed ecologists to express some of the values of ecosystems in metrics (dollars) that are better understood and have a more powerful meaning in public, policy and decision-making contexts (Chan et al., 2012; De Groot et al., 2010). Using the language of ES, it was easier to calculate the long-term cost of losses resulting from the devastation of specific ecosystems – in other words, the price of a lack of sustainability. The ES concept was established by the Millennium Ecosystem Assessment (MEA, 2003, 2005).

The necessity to transform ES issues in monetary value to push for greater environmental sustainable awareness and practices can also demonstrate how the commodification of the environment (as much as of everything else) advanced by the current political-economic system has outdone or obscured what should be obvious not for merely economic reasons but for the obvious well-being of people and the earth.

Another term popularised by MEA is "wellbeing". The MEA perspective links wellbeing directly with the quality of ES. Sustainability is conceptualised here as the efficiency of human wellbeing (Cummins et al., 2003; Knight & Rosa, 2011; Schleicher et. al., 2018). Still, obviously the wellbeing of people depends not only on the ecosystem and services. It also involves material means, good social relations, a sense of agency, subjective feelings and many other factors.

MEA (2005) draws attention to the great importance of ES in reducing world poverty. It highlights that poor people's wellbeing and livelihoods depend directly on ES (Cavendish, 2000; Daw et al., 2011; Fisher, 2004; Fisher et al., 2014). Poverty is defined as an extreme deprivation of wellbeing. Poor people are also more vulnerable to natural hazards (TEEB, 2010).

Since the MEA publications (2003, 2005), ES and wellbeing have received tremendous attention in the academic literature and have featured in a huge number of strategies at supranational and national level, including the Sustainable Tourism Development Goals (UNWTO & UNDP, 2017). For example, the first and foremost directive goal is "no poverty" and "zero hunger". However, despite the growing popularity of the terms ES and wellbeing, there is no agreement on basic questions, such as what wellbeing actually is, how it should be measured for individuals and nations, and what the contribution of specific ecosystems to the wellbeing of specific people might be. The ideal is a situation of win-win outcomes where ES are used for human wellbeing. Still, a meta-analysis of 1 324 potentially relevant reports from different countries shows that there is little understanding of what is required for these outcomes to be achieved (Howe et al., 2014).

Many supranational organisations and governments are engaged in projects and policies dedicated to improve human wellbeing derived from ES. However, The situation becomes vastly more complicated when feedbacks are considered among regions, across spatial extents from local to global, or across time horizons as when short-term decisions affect long-term flows of ecosystem services (Carpenter et al., 2009, p. 1308). It is also recognised that different groups benefit differently. In poor countries, an inadequate ES policy may result in the violation of almost all components of wellbeing – security, freedom of choice and action, and even existence.

When it comes to tourism, the discussion becomes even more difficult. In fact, analysing the impact of tourism on the wellbeing of host communities is more complex than holistically studying dependencies between wellbeing and sustainable development (Helne & Hirvilammi, 2015). This may be because tourism functions as an adjunct to other sectors of the economy in relation to national policies and is connected to the environment (Hopwood, Mellor & O'Brien, 2005; Raudsepp-Hearne et al., 2010).

That tourism impacts ecosystems and wellbeing is self-evident. Tourism is based on ecosystems (they are often the main tourist attraction), uses them and changes the form of their use. The main goal of developing tourism (from the destination perspective) is to generate income; therefore, theoretically, tourism should lead to increased wellbeing for the receiving or host community, at least from a monetary perspective.

The United Nations General Assembly declared the year 2017 the International Year of Sustainable Tourism for Development. Tourism is seen as a driver of development and peace, promoting the harmonious co-existence of people from all countries (Beijing Declaration, 2016). It is assumed that tourism is something positive, conducive to the development of areas in which it takes place and thus improving the wellbeing of their inhabitants.

On the other hand, many researchers in the field of tourism proved the negative impact of this sector on the environment and local culture (e.g. Akama, 2004; d'Hauteserre, 2004; Hall & Tucker, 2004; Deery et al., 2012). Tourism can be predatory or dysfunctional, leading to the opposite of wellbeing, also in relation to ES. Tourists create additional competition for the same services and can hinder, limit or prevent access for locals. Even if the terms wellbeing and ES themselves are not used, they are what the researchers deal with.

As regards tourism, the focus of MEA (2005) is on the contribution of ES to the wellbeing of the final consumer only – that means the tourist. But, as underlined by Daw et al. (2011, p. 374), for … local communities, tourism is effectively a provisioning service for income and employment, allowing their material needs to be met.

This paper aims to compile red flags appearing at the interface of hosts' wellbeing, ES and tourism, which have already been described in the literature. We focus on host communities in developing countries, as poor and disadvantaged people much more often depend directly on ES.

We start with a description of the concepts ES and wellbeing. The second section describes prominent gaps and challenges in the ES–wellbeing interface, with special focus on those that can be relevant to tourism (such as the establishment of protected areas, the concept of paying for ES, poverty reduction, endowments vs entitlements). The third section is devoted to a discussion of the identified gaps and challenges. The last section contains conclusions and implications. The article has no ambition to exhaust the issue – it is a voice in the discussion.

Concepts and terms

First we discuss the theoretical background of the concepts and terms ecosystem services (ES) and wellbeing.

Ecosystem services

The concept of ES was established by the Millennium Ecosystem Assessment (MEA, 2003, 2005). Since then, the number of publications about it and the efforts to put it into practice have increased drastically (Daily & Matson, 2008; De Groot et al., 2010; Fisher et al., 2009; Tallis et al., 2008). MEA (2005) divides ES into provisioning, regulating, cultural and supporting services and defines them with reference to their material or non-material values. Material values are attached to provisioning, regulating and supporting services, whereas non-material values are associated with cultural ecosystem services (CES) (Chan et al., 2012, p. 9). MEA (2005, p. 894) describes CES as non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g., knowledge systems, social relations, and aesthetic values.

Until now, MEA has provided the most comprehensive overview and categorisation of ES; yet, the definition has been criticised (Boyd & Banzhaf, 2007, Chan et al., 2012; Wallace, 2007) because it does not clearly separate the welfare of human beneficiaries from the notions of services, benefits and values (Milcu et al., 2013). An interpretation gap in the notions of ES and CES is also the assumption that certain goods are "generally accessible". This may be true for air quality but not, for example, for drinking water or a beach. The problem with limited resources is particularly noticeable on small islands. Surveys regarding the use of common pool resources (CPR) carried out in different parts of the world prove that exploitation by one user reduces resource availability for others (Ostrom et al., 1999; Polman et al., 2016).

CES listed by MEA also include recreation and ecotourism – recognising that people often choose where to spend their leisure time based on the characteristics of the natural or cultivated landscapes in a chosen area.

ES approaches have become a significant basis for planning and management policies (Chan et al., 2012). Major contributions brought an understanding of the monetary aspects – costs and benefits – of ES delivery (Berkel & Verburg, 2014). Much attention was devoted to landscape studies (Bills & Gross, 2005; De Groot et al., 2010; FAO, 1999; Hein et al., 2006; OECD, 2001; Wilson, 2004), including the mapping of ES, which offered policymakers suggestions about the best locations for service delivery (Egoh et al., 2008; Willemen et al., 2008).

The integration of ecological and economic analysis contributed to payment for ecosystem services (PES) programmes and policies (Eigenraam et al., 2007; Engel et al., 2008; Muñoz-Piña et al., 2008; Turner & Daily, 2008; Turpie et al., 2008). A meaningful contribution to the discussion regarding PES followed the Deepwater Horizon ecological disaster caused by British Petroleum in the territorial waters of Mexico, with the ensuing questions about the cost and who should pay for the damage.

The ES perspective is also evident in the Sustainable Tourism Development Goals (UNWTO & UNDP, 2017), where most categories are described in the language of ecosystems, for example life on land, life below water, climate. The exception is the category of CES, which is not evident here, and cannot be, because of oversimplifying tourism.

Wellbeing

The term wellbeing was first used in economics in the 1930s in relation to the newly coined Gross National Product (GNP) index, which soon evolved into Gross Domestic Product (GDP). According to GNP and GDP indices, the higher the income and expenditure of a given country, the higher the wellbeing of its citizens (Shea, 1976). At the time, economic sciences were seen as most applicable to the study of wellbeing, as the quality of life of any individual or community can in a direct and simple way be related to income (Wilson, 1972, p. 131). Limiting wellbeing only to economic indicators is obviously not enough. The result was a search for new indices adjusted to measuring, mapping and describing differences in culture, social and economic development, including local knowledge (Sheppard et al., 2009). Still, most interpretations were limited to economic sciences, for example the Human Development Index (HDI), which includes longevity and level of education (UNDP, 2003), and the Genuine Progress Indicator (GPI), which differentiates between positive and negative expenses (Halstead 1998; Hamilton, 1998). A more holistic view of wellbeing was introduced by Sen (1985) in his concept of capabilities. The concept encompasses political, social and economic factors.

In more recent papers, any positive correlation between economic factors and human wellbeing (especially subjectively experienced) is often contested (Gardner & Oswald 2007). Surprisingly, it was found that citizens of most Western countries, where GDP is relatively high, do not experience higher subjective wellbeing (SWB) than those of poor countries (Cummins et al., 2003; Eckersley, 1998, 2000a; Shea, 1976). Studies conducted by the University of Bath Research Group on Wellbeing in Developing Countries (WeD), prove that some of the poorest countries, such as Ethiopia and Bangladesh, are characterised by very high SWB among their citizens (Blackmore, 2009; Copestake, 2009; Copestake & Campfield, 2009; Deneulin & McGregor, 2009; White, 2009). The findings can be contested with Appadurai's (2004) concept of capacity to aspire – arguing that poor people do not have enough aspirations and are thus not even aware of their low wellbeing – still, the findings prove that indices of wellbeing, used in a global context, need to be re-evaluated.

Also, Easterlin's (1974, 1995) research shows that (1) within the same community, the SWB of the wealthy is higher than of the poor, but (2) citizens of wealthy societies do not show a higher SWB than citizens of poor countries at all. What is more, (3) if countries increase their wealth, this does not improve the SWB of their inhabitants at all. The results are explained with hedonic adaptation and social comparison. The whole process is known as the Easterlin paradox (Knight & Rosa, 2011).

Cummins and Nistico (2002), in their theory of subjective wellbeing homeostasis, point out the key importance of "expected value". People make comparisons that make them feel worse, better, happier, etc. The key question is, who do they compare themselves to? The importance of relative weights in the wellbeing framework, such as paired comparisons (Saaty, 1980), the expected value method (Janssen, 1994) or the incorporation of community values (Olusoga et al., 2010), is highlighted by many authors.

The MEA (2005) document defines wellbeing as a multivariate state comprising five dimensions: basic material for a good life, health, security, good social relations, and freedom of choice and action. The key challenge is the eradication of global poverty, defined as the extreme deprivation of wellbeing (Carpenter et al., 2009). Poverty is considered to be related to environmental degradation (Raworth, 2012).

The broad categories related to MEA (2005), Maslow (1943), Max-Neef (1991) and Costanza et al. (2007) are developed by Maynard et al. (2010) into the following constituents of wellbeing:

- Existence (E): Basic materials for life – access to water, soil, biota and air
- Health (H): Capacity to cope with change
- Security (S): Coping with constant change at variable rates
- Good social relations (GSR): Achievement of collective benefits at acceptable costs
- Freedom of choice and action (FCA): Ability to choose who, where, what, when and why (Maynard et al., 2010, p. 9).

In research into the connection between wellbeing and tourism, just as for wellbeing itself, various conceptual backgrounds depict wellbeing according to different indices (Dłużewska, 2019).

For example, social science and psychology focus on social change and subjective statements. Here the discussion does not deal with the question "if" tourism has an impact on SWB, but with the role of specific factors in the personal evaluation of the increase or decrease of SWB in host communities.

Economics focus on the percentage of GDP coming from tourism, with the automatic presumption that the higher the GDP, the higher the wellbeing of communities. GDP is the main, official indicator used by WTTC and UNWTO for the impact of tourism on local economies. However, the GDP approach does not consider the distribution of profits or the social stratification caused by tourism. Economists also consider the Quality of Life Index (QoL) as central to research (Huh & Vogt, 2008; Kayat, 2002; Sirakaya, Teye & Sonmez, 2002; Yen & Kerstetter, 2009). According to Derry et al. (2012, p. 66), tourism development influences QoL and so perceptions of tourism growth can be seen as an antecedent of QoL.

Consequently, wellbeing is regarded as increasing thanks to tourism, when employment in this sector is growing and when the material status of communities is rising (Kusluvan, Kulsuvan 2000; Tosun 2000, 2006) , but also when tourism leads to reduced poverty in host communities (Cole 2004; Dłużewska, 2019; Ghimire 2001; Harrison 2001; Scheyvens 2007).

The sustainable tourism guidebook prepared by the World Tourism Organization (UNEP & WTO, 2005) uses the term wellbeing only once, in relation to society, when community wellbeing is discussed. According to the text, community wellbeing comprises: social infrastructure, access to resources, quality of life, quality of environment, as well as a lack of corruption and human-by-human exploitation. The definition comprises environmental and economic components. Although it theoretically stems from the social pillar, its real extent is wider (Dłużewska, 2019).

In the newer guidelines by UNWTO and UNDP (2017), wellbeing is also used only once – this time to support the description of health. However, although wellbeing is scarcely used as a term, its defining features are easily found in nearly all guidelines presented in this document. Here the environmental pillar prevails.

Ecosystem services vs wellbeing

The first message of early ES literature (Daily, 1997) and MEA (2005) was that ES significantly contribute to the wellbeing of people. Changes in ES will automatically translate into changes in wellbeing, meaning that an increase in ES will lead to poverty reduction. MEA (2005) also emphasises that different ES contribute to different aspects of human wellbeing. Since then, many authors have underlined the trade-offs between different ES. Increasing the value of one ecosystem service can lead to lowering the value of other ES (Carpenter et al., 2009; Rodriguez et al., 2006).

It is also emphasised that different groups of people derive benefits from different ES (Daw et al., 2011). In the same place, for some people, wellbeing can be derived from provisioning services, such as fishing. For others – more affluent – it can come from the aesthetic values of the landscape. Dunn (2010) and Fisher et al. (2013) coined the term ecosystem "disservices" – environmental factors that harm human wellbeing.

Benefits exist to different extents. They are related to the individual context and specific mechanism of access. As noted by Daw et al. (2011, p. 371), First … different groups derive well-being benefits from different ES, creating winners and losers as ES change. Second, dynamic mechanisms of access determine who can benefit. Third, individuals' contexts and needs determine how ES contribute to well-being. Therefore the trade-offs between different ES will lead to trade-offs in the wellbeing of different people and communities (Daw et al., 2011; Rodriguez et al., 2006). The dynamics through which people interact around ES are related to "access" and "control" (Fisher et al., 2013; Ribot & Peluso, 2003). None of this is included in the framework created by MEA (2003, 2005).

Important human characteristics of individuals and groups that mediate the relationship between ES and wellbeing are "preferences" (Fisher et al., 2013; Narayan et al., 2000; Sen, 2001) and "capital" (physical, social and human) (Fisher et al., 2013 p. 38):

- Physical capital refers to infrastructure and physical goods that support livelihoods and access to ES (e.g. boats) (Brown et al., 2008).
- Social capital is understood as rules, knowledge, expectations and norms shared within a group – everything that creates activities and interactions perceived as normal (Coleman, 1988; Ostrom, 1990; Ostrom, 2001; Putnam et al., 1993).
- Human capital refers to individual knowledge and skills brought to an activity (Ostrom, 2001, p. 175), which influence the individual's access to ES (Paudyal et al., 2006; Thoms, 2008). Fisher et al. (2013, p. 39) note, As with social capital, human capital differentials have implications for representation in groups controlling resource access.

We can also add financial and natural capital, as in the Sustainable Livelihoods Framework for Rural Development (Scoones, 1998).

Fisher et al. (2013), using the earlier work of Leach et al. (1999) and Sikor and Nguyen (2007), highlight the distinction between "endowments", which are the rights and resources actors have (Leach et al., 1999, p. 233) and "entitlements", which are the means to use a resource. Endowments can be proximity to a forest, for example, or legal, statutory rights to forest products. Entitlements legitimate effective command over the access. To understand this distinction, it may be useful to think about endowments as what can be given (for instance, by a state to its citizens), and entitlements as what can be done with an endowment (Fisher et al., 2013, p. 38). The model proposed by Fisher et al. (2013) also highlights the use of ES by external actors (e.g. during land appropriation).

A common form of ecosystem protection, deemed a type of entitlement, is the creation of legally protected areas (e.g. national parks and reserves).

A specific type of entitlement is payment for ecosystem services (PES), which implicitly recognize[s] the unequal distribution of the costs and benefits of maintaining ES, through monetary compensation from "winners" to "losers" (Daw et al., 2011, p. 371). PES attempts to prevent the formation of socioeconomic disproportions caused by the use of ecosystems. Still, it should be emphasised that ES literature refers to the PES concept to a very limited extent. Also, most attempts to model and quantify ES do not take into account the division into various groups of beneficiaries, thus ignoring the distribution of benefits between groups and individuals in society (Daw et al., 2011). Sometimes very general divisions are adopted, for example social versus private benefits (Polasky et al., 2010) or broad divisions between stakeholders at different scales (Hein et al., 2006).

Poverty is characterised by a lack of choice; therefore we cannot apply "preferences" in this case (Fisher et al., 2013; Narayan et al, 2000; Sen, 2001). As highlighted by Fisher et al. (2013, p. 40):

Households with land endowments (implying collective-choice rights) are more likely to be able to access payments. In contrast, poorer people, if they have access, will tend to rely directly on non-commodified services, more likely through "access and withdrawal", or "management" rights, than through higher order collective-choice rights. Furthermore, those with only operational rights may lose access to the resource when the service is commodified, particularly in "use-restricting". This all serves as caution against assuming that, on the establishment of PES, those who benefit from uncommodified services will automatically benefit from payments for commodified services. Instead, we must pay attention to the mechanisms of entitlement for different ecosystem services.

As stated long ago by Sen (1981), the underlying causes of poverty are social differentiation and social inequality (related to rights, access and entitlements). It cannot therefore be presumed that diversification (in services) will improve the wellbeing of the whole population. It can be exactly the contrary: especially for the poorest, least affluent, it may lead to a decline in wellbeing (Frayne et al. 2013; Coulthard, 2012; Fisher et al., 2013).

The original rationale of ES was to convert ecosystems to monetary values, thus proposing adjusted market prices (Bateman et al., 2011). Such valuations could also help PES policies and pro-poor actions. Still, as pointed out by Daw et al. (2011, p. 375), although cash and employment are clearly an (perhaps the most) important mechanism for poverty alleviation, much of the ES literature has surprisingly little emphasis on these.

To create policies, it is also crucial to distinguish different "groups of poor", depending on people's functional relation to ES and PES schemes, such as sellers, final consumers (users) and non-participants (Daw et al., 2011; Wunder, 2008). Improving the wellbeing of some groups is not achieved by increasing the quality or flows of ES, but through facilitating their access (Daw et al., 2011, p. 373).

The perspective of wellbeing – as being derived from and dependent on the environment – was later supported by many academics in the field of tourism (Hall, Scott & Gössling, 2013; Tuula & Tuuli, 2015). However, a vast body of research encompasses consequences on a more global scale (Hall et al., 2013), for example studies calculating gas emissions produced by air carriers (De Bruijn et al., 2010; Dwyer et al., 2010; Pearch-Nielsen et al., 2010; Gössling, & Peeters,, 2007; Scott et al., 2008, 2010). As Dłużewska states (2019, p. 517), As a result we start perceiving air travel as not sustainable, as negatively impacting wellbeing of the whole planet, because pollution is increasing due to overabundant jet propulsion.

Gaps and challenges

Analysing the role of ES in the wellbeing of tourism destination hosts can definitely not be limited to cultural ecosystem services (CES) only, within which tourism was placed in the MEA document (2003, 2005). The analysis must also include provisioning, regulating and supporting services, thus – in practice – the whole spectrum of ES listed in the MEA document. Below we discuss the most frequently noted gaps and problems caused by tourism, which concern ES and affect the wellbeing of the host community, such as environmental destruction, common pool resources (CPR), social capital and social change.

Tourism and environmental destruction

In many places the prospect of a fast return on investment in tourism leads to overexploitation and even to irreversible destruction of ecosystems, for example by municipal waste disposal and dumping into the sea, devastation of coral reefs by free anchoring around islands, and off-road activities contributing to erosion (Honey, 1999).

In destinations where ecosystems are an important tourist attraction, the risk is twofold. The destruction of ecosystems not only deprives the hosts of the benefits of these but also reduces the attractiveness of the place to tourists. Tourists give up visiting such a destination. As a result, the hosts are also deprived of income from tourism. The problem was already recognised in 1986 in the Caribbean and is called "self-destruction by tourism" (Shaw & Williams, 1996). Bearing in mind that the number of international tourists multiplied from 25 million to 1,5 billion between 1950 and 2019, and the number of domestic tourists is now 6 billion a year, we can see that the risk is much greater.

The literature also proves that environmental destruction is not only related to mass tourism, but practically to any type of tourist activity. Exceeding the destination's carrying capacity and straining inadequate access mechanisms are the critical factors. For example, it is now recognised that ecotourism, which for long was perceived as the most sustainable, can have a worse impact than stationary leisure tourism (Duffy, 2013; d'Hauteserre & Funck, 2016). In principle, ecotourism is based on ecosystems; as such it inevitably disturbs their balance (Duffy, 2013; Dłużewska & Giampiccoli, 2020). Another finding is that ecotourism can be a part of mass tourism, not necessarily its opposite (Duffy, 2013). Also, it often occurs in destinations where tourist infrastructure does not exist, so tourists are not able to spend money there. Consequently, the potential income "leaks out" (Gibson, 2010).

Tourism and social capital

Tourism can be harmful due to undesirable behaviour by stakeholders, tourists or the host community (Russell & Wallace, 2004; Wu et al., 2020). Harm done by the hosts is largely determined by their level of knowledge and economic condition. Aref and Redzuan (2009), Calanog et al. (2012), Manyara (2007), Suansri (2003, 2005), Giampiccoli and Mtapuri (2020) recognise the problem of limited capacity at community level, and therefore the requirement of capacity building. Giampiccoli et al. (2020) point out that capacity building should be the first step in community-based tourism (CBT) projects. Thus, before developing CBT …, it is necessary to prepare and build the capacity of the host community (Suansri, 2005, p. 12). Although the discussion is about CBT, it can largely be extended to developing tourism in general.

Social capital is expectations and norms shared within a group and perceived as normal (Ostrom, 2001). It has important implications for policies on ecosystem services (ES) and tourism, even in areas with high levels of economic development. An example is Nordic countries (Norway, Greenland, Iceland, Sweden), where the conviction is culturally rooted that access to ecosystems is a human right.

Proposals to introduce any restrictions on access to ES (whether via PES or entitlements) are met with great resistance here. With the current level of world tourism, this poses a serious risk of ecosystem destruction for two main reasons: first, there is the danger of exceeding the limits of tourism capacity and inappropriate behaviour by tourists, who do not share the instilled respect for ecosystems that the local population has. Second, the universal access for "strangers" (tourists) does not make it possible to generate an economic return based on the main "tourist" attraction in these destinations.

Tourism and social change

As stated before, a crucial aspect of subjective wellbeing is individual expectations and the capacity to aspire (Appadurai, 2004). As a result of comparing themselves to others, people feel rich or poor, socially accepted or not, etc. It is widely recognised that tourism radically changes the reference point for comparisons in many fields. Especially in developing countries, where there is a large material gap between tourists and the local population, the comparison leads to a lowering of self-esteem in locals (Middleton, 2004; Peake, 1989; Tosun, 2001a, b).

Tourists – even if they are disliked – are seen as "rich, successful people"; therefore their behaviour is considered an indicator by many host communities (Peake, 1989). This can lead directly to imitation of tourists' behaviours by their hosts. Sometimes these behaviours are positive or completely neutral, but many times negative cultural behaviours (such as alcohol abuse, sexual freedom) are copied. Also included is their attitude towards the environment. An example is the increased consumption of water (even from 8 litres to 500 litres per day) by inhabitants of desert areas in Tunisia and Morocco (Dłużewska 2008, Dłużewska et al., 2013). As a result of observing the behaviour of tourists, many locals had the false belief that water resources were inexhaustible, and that in the past the technology to use them had simply been lacking. Moreover, the local population wasted water to a much greater extent that tourists, for example by using potable water to irrigate fields, or – in the case of tourism – building hotels with swimming pools in desert areas, and even making daily water changes in these pools (Dłużewska, 2008).

Tourism and common pool resources

Tourism increases the number of ES users, sometimes very considerably – to the extent that it limits or even deprives locals of access to ecosystems. Tourism introduces significant competition for common pool resources (CPR). The financial capacity of the hospitality sector, especially in poor countries, is higher than the local community's financial means. As a result, competition for the most attractive – limited – space (e.g. access to the beach) generates the risk of fraud and corruption.

Tourism, through severe competition for use, changes the policy of access to ES from endowments to entitlements. This carries a high risk of depriving the poorest of access. Examples of such a process are visible in many areas around the world (Cohen 2010, 2011). Even ecological disasters can be a pretext for abuse; for example, after the tsunami on 26 December 2004, expropriation affected the poorest inhabitants on the coasts of Thailand. The official explanation was the failure to regulate the legal issues of land ownership (Cohen, 2011).

Discussion

In many destinations, especially in developing countries, increasing economic indices of wellbeing occurs at the cost of culture and the environment. Better financial possibilities for locals often lead to replacement of thatched roofs with corrugated metal sheets, abandoning traditional dwellings for modern houses, and overexploitation of ecosystems. Numerous studies prove that an increase in income of ecologically unaware societies leads directly to an increase in the volume of waste, overexploitation of natural resources, and so on (Dłużewska, 2019, p. 517). Tourism is an important incentive for harmful behaviours, such as the creation of golf courses to meet the needs of tourists, even at destinations with an extreme lack of water. Such negative behaviours were the reason for introducing "responsible consumption and production" in UNWTO guidelines for sustainable tourism.

Facing such environmental destruction, supranational organisations and governments of receptive destinations take various steps to protect ecosystems. Most initiatives involve the creation of protected areas (Fisher et al., 2014). In practice, numerous problems occur with regard to the governance of them and intense competition about the options for their use (Bass & Dalal-Clayton, 1995; Polman et al., 2016). Protecting areas in principle restricts access to common pool resources (CPR). This leads to social conflicts, especially at a local level, with a clash between individual and community, local and global, short-term and long-term interests (Bonaiuto et al., 2002). Sometimes it deprives local people of their livelihoods, alters their lifestyle and, hence, reduces their wellbeing. Negative effects of creating protected areas are usually borne by the poorest. And this, in turn, undermines the fundamental goal of MEA and sustainable development – the fight to reduce poverty. Surveys regarding the impact of tourism on poverty reduction confirm that the creation of (Marine) Protected Areas in places that are attractive to tourists can actually undermine local wellbeing and impoverish sectors of the population as they lose entitlements to resources important for maintaining their livelihoods (Scheyvens & Momsen, 2008, p. XX; Stonich, 2003).

Similarly, in Kenya, the establishment of a marine protected area reduced the overall number of fishers in the area who benefited from fisheries (McClanahan & Kaunda-Arara, 1996), while likely improving opportunities for tourism revenue. Some fishers lost their livelihoods, while others who had skills and opportunities to benefit from tourism improved their well-being through new employment opportunities." (Daw et al., 2011, p. 372)

We should also refer to an important paradox, indicated in the same MEA (2005) document: despite the large global declines in most ecosystem services (ES), human wellbeing has increased. This contradicts the claims of environmentalists, and MEA itself, that ecological degradation will lead to declines in wellbeing (Raudsepp-Hearne et al., 2010). Knowledge of the reason for this paradox is of primary importance when talking about the ES–wellbeing relationship. It could initially be explained with the use of incorrect measures. However, Raudsepp-Hearne et al. (2010) assess more explanations for these divergent trends. First, well-being is dependent on food services, which are increasing, and not on other services that are declining (p. 576). Second, technology has decoupled well-being from nature, and finally, time lags may lead to future declines in well-being (p. 585).

Research also indicates that people prioritise cash from the sale of ecosystem products over mere access to ES (see Brown et al., 2008 for coastal communities). This insight is very relevant to tourism. Sustainable tourism development policies should enable the host community to sell ecosystem products. This will not only increase the wellbeing associated with ES, but also improve their perception of tourists, who would be seen as a source of potential benefits, not competition for ES. However, this does not mean that ecosystem products should be allowed to be sold indiscriminately without any rules and/or limits, but that host community, including the disadvantaged members of society, should as anyone else also have the right – within specific (possibly enforceable) regulations consistently and comprehensively entrenched in sustainability strategies – to use and sell ecosystem products. Besides being embedded in the suitability approach these regulations could also make difference in usage and selling rights between local (permanent residents) and outsiders thus considering that host community members (the permanent residents), importantly with special attention to the poor strata of society, are the ones attached to a place in a long-term basis, not just for a 'holiday' time, thus the ones that will bear the possible cost of ES degradation.

Regarding the fact that wellbeing is based on material means and that, especially for poor people, the revenue from ecosystems (cash) is of great importance, the discussion leads to the payment for ecosystem services (PES) concept, which is the mechanism to protect ecosystems and support the losers through monetary compensation from winners. With reference to many ecosystems (e.g. coral reef, coast, water), this concept can have broad practical applications. What is surprising, in sustainable tourism literature, is that PES is almost not recognised, and yet this is the field where it could bring significant profits for locals. In tourism literature, the recommendations are basically about increasing taxes paid by stakeholders (De Blaeij et al., 2011; Polman et al., 2016). However, in the author's opinion, the effect of tax increases can be negative. First, in many destinations (especially developing countries) there is a huge group of actors who do not pay taxes at all. Second, some tourism actors (e.g. cruise companies) do not spend money at the destination at all, or just to a very limited extent. Increasing taxes would be an additional burden on stakeholders who are already paying them.

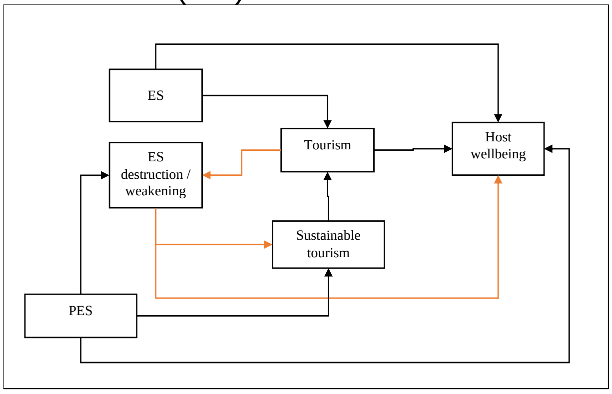
Undoubtedly, any policy intervention in the context of direct benefits from uncommodified services requires a holistic understanding of the implication of payment schemes. This makes clearer the trade-offs between gains in wellbeing from payments, versus possible losses of access to direct services that payments are contingent upon (Fisher et al., 2014; p. 40). Before implementing any PES policy, modelling and mapping of ES trade-offs are needed (Bateman et al., 2011; Daw et al., 2011; Nelson et al., 2009). Only Where income data of beneficiaries are available, financial benefits from ES can be put into individual context, by applying the rarely-used tool of equity weights to ES costs and benefits (Daw et al., 2011, p. 377).

Still, implementation of PES in many destinations is difficult due to oligarchy and lobbying by tour operators. Implementing PES is associated with the risk of corruption. This is especially true for countries with high levels of poverty. In this case, PES may further restrict access by the poorest to the use of ES and thus aggravate poverty (Daw et al., 2011; Fisher et al., 2014; Kosoy & Corbera, 2010; Schlager & Ostrom, 1992; Wunder, 2007).

An additional complication is the already mentioned Easterlin paradox (1974, 1995). Thus, even if the material level rises, it does not mean that people's wellbeing will rise in the same way. Moreover, in developing countries – exactly where the problem of poverty is most evident – wealth as such does not play a key role in people's subjective wellbeing. Respect for tradition, good social relations and social respect play a more important role here (Blackmore, 2009; Copestake, 2009; Copestake & Campfield, 2009; Deneulin & McGregor, 2009; White, 2009). Moreover, as proved by the studies conducted by Wellbeing in Developing Countries (WeD), there are two juxtaposing planes for wellbeing:

1. Doing well means feeling good → typical for Western societies
2. Doing good means feeling well → typical for developing countries (White, 2009, p. 4)

WeD's founding shows that "doing" is a key component of "being" in developing countries (see also Tuula & Tuuli, XXX). "Feeling well" requires the freedom for "doing". In this context, any entitlement replacing endowments will reduce the capabilities and sense of agency. Therefore, the most advantageous policies for community development are those that will either enable traditional endowments or enable local communities, especially the poorest, to "participate" in tourism somehow. However, community development must be understood in an all-inclusive perspective – going beyond statistical poverty data (Giampiccoli & Saayman, 2017). Also, capacity building is first required. We should agree with Giampiccoli and Saayman (2017) or Shang-Pao and Fotiadis (2014) that the most advantageous type of tourism organisation in this context is community-based tourism (CBT).



Legend: Red line – negative impact, destruction
Black line – positive or potentially positive influence

Fig. 1 Ecosystem services - host wellbeing - sustainable tourism relationship model

Conclusions and implications

Tourism has an important influence on the wellbeing of host communities – their income, self-esteem and capacity to aspire. For hosts, tourism plays a role of provisioning service for employment and income. At the same time, tourism reduces access to ES for many groups (especially the poor); it uses ecosystems and often destroys them. The literature widely acknowledges case studies where improper management of tourism led to the self-destruction of the destination or had a negative impact on local culture and the environment. In many cases, tourism deepens social disproportions and worsens the situation of the poorest (XXXX). Careful planning is crucial here, before the damage is done.

The role of planning is also underlined in regard to poverty (Angelsen & Wunder, 2003; Fisher et al., 2013; Mayers, 2007). As Fisher et al. (2013, p. 37) state, Poverty alleviation and human wellbeing ecosystem services are just as, if not more, likely to be associated with prevention than reduction.

The management of ES (protection or restrictions) is not easy in the face of the conflicting needs of different groups (Ostrom et al., 2009). A starting point is to define the level of ES access and benefits of different stakeholder groups. Knowledge in this regard is essential to evaluate management options and establish acceptable trade-offs. Tackling this gap means seeking to understand the diversity of stakeholders, why they use various ecosystem services, and the potential social conflicts that can arise from the use of specific ecosystem services by different individuals and stakeholder groups at different spatial-temporal scales (Bennett et al., 2015, p. 80). We should agree with Howe et al. (2014, p. 263) that Taking account of why trade-offs occur (e.g. from failures in management or a lack of accounting for all stakeholders) is more likely to create win-win situations than planning for a win-win from the outset.

The consideration of social differentiation in the access to ES is central in understanding what the contribution of ES to wellbeing is. We cannot talk about any contribution in cases where people have no access to the services (Fisher et al., 2013).

The MEA framework, introducing the "philosophy" of monetary value of ecosystems, and recognising the complexity of human wellbeing, can be very useful in tourism research and tourism policies. It requires, however, numerous clarifications. The concept has been criticised for overlooking issues related to the political economy and social differentiation (Daw et al., 2011; Fisher et al., 2013) and for oversimplifying the relationships between wellbeing and nature (Lele et al., 2013). Fisher et al. (2013) also point out that social trade-offs in ecosystem management strategies have been totally neglected.

Unfortunately, MEA (2005) did not consider definitions and findings elaborated by the United World Tourism Organization and did not take advantage of the abundant literature on tourism. As a result, the document generates much misunderstanding, which makes it difficult to properly manage the tourism sector on its basis.

As already stated, in the ES categories created by MEA, tourism is located among different CES (as recreation and ecotourism). However, these problems need to be looked at from a much wider perspective, even if we are talking only about tourists. First, the beneficiaries and recipients of ES are not only participants in ecotourism. Benefits are taken to the same extent by participants in most of other tourism types (leisure, sightseeing, cruising, even partying – which is often done on beaches). Second, the approach presented in MEA does not distinguish the size of tourism (e.g. individual vs mass tourism), which is essential for the carrying capacity of any territory, even cities. When tourism is based on ecosystems, carrying capacity is crucial. Third, there is no distinction between tourism and recreation. The two categories have been mixed up and treated equally (also in many strategies and policies inspired by MEA). This makes a tremendous difference in the income of host communities. Participants in recreation do not stay at the destination even a single night. They can explore the place without spending a dollar.

Indeed, in order to implement adequate policies for ES in tourism (with due regard to host population wellbeing) researchers should acknowledge the wide background in tourism literature. In fact most ES researchers using the term "tourism" do so "outside" the mother discipline (e.g. with no recognition of what tourism or recreation is) (see Milcu, 2013; Dłużewska, 2016, for examples). This makes it impossible to introduce proper policies based on research findings.

On the other hand, in the tourism literature (and policies), there is still very little use of ES and CPR findings, which would help to consider the environment in a more market-related manner. In the author's opinion, the PES concept, in particular, can be very advantageous for host destinations (both for ecosystems and communities' wellbeing). PES could provide legislative solutions allowing all visitors to contribute to local economies. It could also incorporate differentiations; for example, fees for one-day visitors should be higher than for tourists who spend money at the destination for accommodation and meals.

In conclusion, in order to develop tourism that respects ES and host wellbeing, we suggest the following:

1. Modelling and mapping ES trade-offs coupled with stakeholder analysis to identify resulting distributional and financial impacts
2. Better acknowledgement of PES in the field of tourism literature and polices
3. Better acknowledgement of tourism literature in the field of ES literature and policies
4. Better acknowledgement of wellbeing literature in the field of tourism and ES research and policies
5. Recognising differences in wellbeing planes (e.g. for developing countries)
6. Giving priority to endowment policies (especially for the poor)
7. Giving – guaranteeing – poor people same rights/entitlement of sell opportunities of ecosystem products
8. Protecting host (permeant resident - specifically poor people) against outsiders in the usage/selling (entitlement) of Ecosystem products
9. Consistently and comprehensively entrench Ecosystem products entitlement within an enforceable regulative framework based on suitability.
10. Developing the form of tourism that provides and incentive to develop local capacities (such as CBT)
11. Investing in capacity building

These recommendations are global and fairly general indications that should be considered at the interface between ES, tourism and wellbeing policies, whatever the context.

Funding

This research received no external funding.

Author contribution

Conceptualization: A.D.; methodology: A.D., Z.P.; formal analysis: A.D.; investigation: A.D., A.G.; writing—original draft preparation: A.D.; writing—review and editing: A.D., Z.P., A.G. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

Akama, J. S. (2004). Neo-colonialism, dependency and external control of Africa's tourism industry. Akama JS Tourism and postcolonialism: Contested discourses, identities and representations. London: Routledge, 140-152.

Angelsen, A.,Wunder,S., (2003). Exploring the Forest–Poverty Link: Key Concepts, Issues and Research Implications. Pages viii, 58 p. *Key Concepts, Issues and Research Implications*. CIFOR, Bogor, Indonesia.

Appadurai, A. (2004). The capacity to aspire. Culture and the Term of Recognition, in: *Cultural politics in a Global Age. Uncertainty, Solidarity and Innovation*, ed. Rao V., Walton M., Oneworld Publications, Oxford, 29-35.

Aref, F., & Redzuan, M. (2009) Community Leaders' Perceptions toward Tourism Impacts and Level of Community Capacity Building in Tourism Development. *Journal of Sustainable Development*, 2(3), 208-213.

Bateman, I.J., Mace, G.M., Fezzi, C., Atkinson, G. & Turner, K. (2011) Economic analysis for ecosystem service assessments. Environmental Resource Economics, 48: 177–218.

Bass, S., & Dalal-Clayton, D. B. (1995). Small island states and sustainable development: strategic issues and experience (Vol. 3). London: Environmental Planning Group, International Institute for Environment and Development.

Beijing Declaration on Sustainable Tourism as a retriver fro Development and Peace (2016) retrived from - https://www.e-unwto.org/doi/epdf/10.18111/unwtodeclarations. 2016.25.01

Bennett, E. M., Cramer, W., Begossi, A., Cundill, G., Díaz, S., Egoh, B. N., ... & Lebel, L. (2015). Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. *Current Opinion in Environmental Sustainability*, 14, 76-85.

Berkel, D. B., & Verburg, P. H. (2014). Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. *Ecological indicators*, 37, 163-174

Bills, N., & Gross, D. (2005). Sustaining multifunctional agricultural landscapes: comparing stakeholder perspectives in New York (US) and England (UK). Land Use Policy, 22(4), 313-321.

Blackmore S. (2009). Responsible wellbeing and its Implications for Development Policies. WeD Working Paper 09/47.

Bonaiuto, M., Carrus, G., Martorella, H., & Bonnes, M. (2002). Local identity processes and environmental attitudes in land use changes: The case of natural protected areas. *Journal of economic psychology*, 23(5), 631-653.

Boyd, J., & Banzhaf, S. (2007). What are ecosystem services? The need for standardized environmental accounting units. *Ecological economics*, 63(2-3), 616-626.

Brown, K., Daw, T., Rosendo, S., Bunce, M. & Cherrett, N. (2008). Ecosystem services for poverty alleviation: marine and coastal situational analysis. Synthesis report. Natural Environment Research Council (NERC)/Department for International Development (DFID), UK.

Calanog, L.A., Reyes, D.P.T., & Eugenio, V.F. (2012). Making Ecotourism Work. A Manual on Establishing Community-based Ecotourism Enterprise (CBEE) in the Philippines. Philippines office: Japan International Cooperation Agency.

Chan, K. M., Satterfield, T., & Goldstein, J. (2012). Rethinking ecosystem services to better address and navigate cultural values. *Ecological economics*, 74, 8-18.

Carpenter, S. R., Mooney, H. A., Agard, J., Capistrano, D., DeFries, R. S., Díaz, S., ... & Whyte, A. (2009). Science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. Proceedings of the National Academy of Sciences, 106(5), 1305-1312.

Cavendish, W., (2000). Empirical regularities in the poverty–environment relation- ship of rural households: evidence from Zimbabwe. World Development 28 (11), 1979–2003.

Cohen, E. (2010). Tourism crises: A comparative perspective. *International Journal of Tourism Policy*, 3(4), 281-296.

Cohen, E. (2011). Tourism and land grab in the aftermath of the Indian Ocean tsunami. *Scandinavian Journal of Hospitality and Tourism*. 11(3), 224-236.

Cole S. (2004). Shared benefits: longitudinal research in eastern Indonesia. In Qualitative research in Tourism: Ontologies, Epistemologies and Methodologies, Phillimore J, Godson L (eds). Routledge: London; 292-310.

Coleman, J., (1988). Social capital in the creation of human capital. *American Journal of Sociology,* 94 (supplement), 95–120.

Costanza, R., Fisher, B., Ali, S., Beer, C., Bond, L., Boumans, R., Danigelis, N.L., Dickinson, J., Elliott, C., Farley, J., Gayer, D.E., Glenn, L.M., Hudspeth, T., Mahoney, D., McCahill, L., McIntosh, B., Reed, B., Rizvi, S.A.T., Rizzo, D.M., Simpatico, T., Snapp, R., (2007). Quality of life: an approach integrating opportunities, human needs, and subjective wellbeing. *Ecol. Econ*. 61, 267–276.

Copestake J. (2009). Development and Wellbeing in Peru: Comparing Global and Local Views. WeD Working Paper 09/48.

Copestake J., Campfield L. (2009). Measuring subjective wellbeing in Bangladesh, Ethiopia, Peru and Thailand using a personal life goal satisfaction approach. WeD Working Paper 09/45.

Coulthard, S., (2012). Can We Be Both Resilient and Well, and What Choices Do People Have? Incorporating Agency into the Resilience Debate from a Fisheries Perspective. *Ecology and Society* 17 (1).

Cummins, R. A., & Nistico H. (2002). Maintaining life satisfaction: the role of positive cognitive bias, *Journal of Happiness Studies* 3, 37–69.

Cummins, R. A., Eckersley, R., Pallant, J., Van Vugt, J., & Misajon, R. (2003). Developing a national index of subjective wellbeing: The Australian Unity Wellbeing Index. *Social indicators research*, 64(2), 159-190.

Daily, G.C (ed), 1997, Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC, 392 pp.

Daily, G. C., & Matson, P. A. (2008). Ecosystem services: from theory to implementation. Proceedings of the national academy of sciences, 105(28), 9455-9456.

Daw, T., Brown, K., Rosendo, S., Pomeroy, R., (2011). Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environmental Conservation* 38, 370–379.

Deery M, Jago L, Fredline L. (2012). Rethinking social impacts of tourism research: A new research agenda. *Tourism Management* 33(1): 64-73.

de Blaeij, A. T., Polman, N., & Reinhard, S. (2011). Economic governance to expand commercial wetlands: within-and cross-scale challenges. *Ecology and Society*, 16(1).

de Bruijn K, Dirven R, Eijgelaar E, Peeters P. 2010. Travelling Large in 2008. The Carbon Footprint of Dutch Holidaymakers in 2008 and the Development since 2002. NHTV Breda University of Applied Sciences, NRIT Research, NBTC–NIPO Research: Breda, The Netherlands.

De Groot R.S., Alkemade R., Braat L., Hein L., Willemen L (2010). Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making, in: Ecological Complexity, 7(3), 260-272.

Deneulin S, McGregor J.S. (2009). The capability approach and the Politics of the Social Conception of wellbeing. WeD Working Paper 09/43

d'Hauteserre, A. M. (2004). Postcolonialism, colonialism, and tourism. A companion to tourism, 235-245.

d' Hauteserre, A. M., & Funck, C. (2016). Innovation in island ecotourism in different contexts: Yakushima (Japan) and Tahiti and its Islands. Island Studies Journal, 11(1), 227-244.

Dluzewska A. (2008). Direct and indirect impact of tourism industry on drylands: the example of Southern Tunisia. *Management of Environmental Quality*, 19(6): 661-669.

Dłużewska A. (2016). Cultural ecosystem services – Framework, Theories and Practices. Problemy ekorozwoju – Problems of Sustainable Development 12(1): 101-110.

Dłużewska, A. M. (2019). Well‐being versus sustainable development in tourism - The host perspective. *Sustainable Development*, 27(3), 512-522.

Dłużewska A., Bollason K., Dłużewski M., Fidelus J. (2013): Nature-based Tourism in Desert Areas: Challenges for Tourism Education (w:) Aitchison C. (red) Education and Outdoor Learning: Adventure, Tourism and Sustainable Development, LSA Publication nr 122

Dłużewska, A., & Giampiccoli, A. (2020) Enhancing island tourism's local benefits: A proposed community‐based tourism‐oriented general model. Sustainable Development.

Duffy, R. (2013). A trip too far: Ecotourism, politics and exploitation. Routledge. Ecosystems and Human Well-Being: A Framework for Assessment. 2003. In Millennium Ecosystem Assessment. Island Press: Washington DC.

Dunn, R.R., (2010). Global mapping of ecosystem disservices: the unspoken reality that Nature sometimes kills us. Biotropica 42(5), 555–557

Dwyer L, Forsyth P, Spurr R, Hoque S. (2010). Estimating the carbon footprint of Australian tourism. Journal of Sustainable Tourism 18: 355–376. DOI: 10.1080/09669580903513061

Easterlin, R., (1974). Does economic growth improve the human lot? Some empirical evidence. In: David, P.A., Reder, M.W. (Eds.), Nations and Households in Economic Growth. Academic Press, New York, 89–125.

Easterlin, R., (1995). Will raising the incomes of all increase the happiness of all? Journal of Economic Behavior and Organization 27, 35–47

Eckersley, R. (1998). Perspectives on progress: economic growth, quality of life and ecological sustainability, In (Ed.) Eckersley R., Measuring Progress: Is Life Getting Better? 3–34. CSIRO Publishing, Melbourne.

Eckersley, R. (2000). The mixed blessings of material progress: diminishing returns in the pursuit of happiness, Journal of Happiness Studies 1, 267–292.

Egoh, B., Reyers, B., Rouget, M., Richardson, D. M., Le Maitre, D. C., & van Jaarsveld, A. S. (2008). Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment, 127(1-2), 135-140.

Eigenraam, M., Strappazzon, L., Lansdell, N., Beverly, C., & Stoneham, G. (2007). Designing frameworks to deliver unknown information to support market-based instruments. Agricultural Economics, 37, 261-269.

Engel, S., Pagiola, S., & Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. Ecological economics, 65(4), 663-674.

FAO, (1999). Cultivation our futures. FAO/Netherlands Conference on the Multifunctional Character of Agriculture and Land. FAO/LNV, Maastricht, The Netherlands.

Fisher, M., (2004). Household welfare and forest dependence in Southern Malawi. *Environment and Development Economics* 9, 135–154.

Fisher, B., Turner, R. K., & Morling, P. (2009). Defining and classifying ecosystem services for decision making. *Ecological economics*, 68(3), 643-653.

Fisher, J.A., Patenaude, G., Meir, P., Nightingale , A.J., Rounsevell, M.D.A., Williams, M., Woodhouse, I.H., (2013). Strengthening conceptual foundations: analysing frameworks for ecosystem services and poverty alleviation research. Global Environmental Change 23(5), 1098–1111.

Frayne, B., Moser, C., & Ziervogel, G. (Eds.). (2013). Climate change, assets and food security in Southern African cities. Routledge.

Gardner, J., & Oswald A.J (2007). Money and mental wellbeing: A longitudinal study of medium-sized lottery wins. Journal of health economics 26(1): 49-60.

Ghimire KB. (2001) (ed.). The native tourists: mass tourism in developing countries. Earthscan: London.

Giampiccoli A; Mtapuri O., Dłużewska A. (2020). Interrogating the intersection between sustainable tourism and community-based tourism, Tourism. An International Interdisciplinary Tourism: An International Interdisciplinary Journal, 68(4), 415-433.

Giampiccoli, A. & Mtapuri, O. (2020). Towards a coalescence of the community-based tourism and 'Albergo Difusso' tourism models for Sustainable Local Economic Development. African Journal of Hospitality, Tourism and Leisure, 9(1), 1-20.

Giampiccoli, A., & Saymaan, M. (2017). Community-based tourism, responsible tourism, and infrastructure development and poverty. Afr J Hosp Tour Leisure, 6, 1-28.

Gibson, C. (2010). Geographies of tourism:(un) ethical encounters. Progress in Human Geography, 34(4), 521-527.

Gössling, S., & Peeters, P. (2007). 'It does not harm the environment!'An analysis of industry discourses on tourism, air travel and the environment. Journal of Sustainable Tourism, 15(4), 402-417.

Hall, M.C., & Tucker, H. (Eds.). (2004). Tourism and postcolonialism: Contested discourses, identities and representations. Routledge.

Hall, C. M., Scott, D., & Gössling, S. (2013). The primacy of climate change for sustainable international tourism. Sustainable Development, 21(2), 112-121.

Halstead, T. (1998). The science and politics of new measures of progress: a United States perspective', In (Ed.) Eckersley, R. Measuring Progress: Is Life Getting Better? (pp. 53–68). CSIRO Publishing, Melbourne.

Hamilton, C. (1998). Measuring changes in economic welfare: the genuine progress indicator for Australia, In (Ed.) Eckersley, R. Measuring Progress: Is Life Getting Better? (pp. 69–92). CSIRO Publishing, Melbourne.

Harrison D. (2001) (ed.). Tourism in less developed world: Issues and case Studies. CABI Publishing: Wallingford.

Hein, L., Van Koppen, K., De Groot, R. S., & Van Ierland, E. C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. Ecological economics, 57(2), 209-228.

Helne, T., & Hirvilammi, T. (2015). Wellbeing and sustainability: A relational approach. Sustainable Development, 23(3), 167-175.

Honey, M. (1999). Ecotourism and sustainable development. Washington, DC: Island Press.

Hopwood, B., Mellor, M., & O'Brien, G. (2005). Sustainable development: mapping different approaches. Sustainable development, 13(1), 38-52.

Howe, C., Suich, H., Vira, B., & Mace, G. M. (2014). Creating win-wins from trade-offs?

Ecosystem services for human well-being: a meta-analysis of ecosystem service trade-offs and synergies in the real world. Global Environmental Change, 28, 263-275.

Huh, C., & Vogt, C. A. (2008). Changes in residents' attitudes toward tourism over time: A cohort analytical approach. Journal of Travel Research, 46(4), 446-455.

Jansen, R. C. (1994). Controlling the type I and type II errors in mapping quantitative trait loci. Genetics, 138(3), 871-881

Kayat K. (2002). Power, social exchanges and tourism in Langkawi: rethinking resident perceptions. International Journal of Tourism Research, 4: 171-191.

Knight, K. W., & Rosa, E. A. (2011). The environmental efficiency of well-being: A cross-national analysis. Social Science Research, 40(3), 931-949.

Kosoy, N. & Corbera, E. (2010) Payments for ecosystem services as commodity fetishism. Ecological Economics, 69: 1228–1236.

Kusluvan S, Kulsuvan Z. (2000). Perceptions and Attitudes of Undergraduate Tourism Students Towards Working in the Tourism Industry in Turkey. Tourism Management 21(3): 251-269.

Leach, M., Mearns, R., & Scoones, I. (1999). Environmental entitlements: dynamics and institutions in community-based natural resource management. World development, 27(2), 225-247.

Lele, S., Springate-Baginski, O., Lakerveld, R., Deb, D., & Dash, P. (2013). Ecosystem services: origins, contributions, pitfalls, and alternatives. Conservation and Society, 11(4), 343-358.

Marjavaara, R. (2007). Route to destruction?: second home tourism in small island communities. Island studies journal, 2(1), 27-46.

Maslow, A. (1943). A theory of human motivation. Psychological Review, 50(4): 370–396

Max-Neef, M. (1991) Human scale development: conception, application and further reflections. The Apex Press, New York, USA

Mayers, J., (2007). Forests and the Millennium Development Goals. Could do better! Editorial in European Tropical Forest Research Network, 47–48, Wageningen, 7–14.

McClanahan, T.R. & Kaunda-Arara, B. (1996) Fishery recovery in a coral-reef marine park and its effect on the adjacent fishery. Conservation Biology 10: 1187–1199.

MEA, (2003). Millennium Ecosystem Assessment, Ecosystems and Human Well- being: A Framework for Assessment. Island Press.

MEA. (2005). Millennium Ecosystem Assessment: Ecosystems and Human Well- being: Synthesis., Washington, DC.

Middleton, J. (2004). Aspects of tourism in Kenya. Anthropology Southern Africa, 27(3-4), 65-74.

Milcu, A. I., Hanspach, J., Abson, D., & Fischer, J. (2013). Cultural ecosystem services: a literature review and prospects for future research. Ecology and Society, 18(3), 4

Muñoz-Piña, C., Guevara, A., Torres, J. M., & Braña, J. (2008). Paying for the hydrological services of Mexico's forests: Analysis, negotiations and results. Ecological economics, 65(4), 725-736

Narayan, D., Chambers, R., Shah, M.K., Petesch, P., (2000). Voices of the Poor: Crying Out for Change. Oxford University Press, Oxford.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D., Chan, K.M., Daily, G.C., Goldstein, J., Kareiva, P.M.,Lonsdorf, E.,Naidoo, R.,Ricketts,T.H.&Shaw, M. (2009). Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7: 4–11.

OECD, (2001). Multifunctionality. Towards An Analytical Framework. Paris, p. 159.

Olusoga, P., Butt, J., Maynard, I., & Hays, K. (2010). Stress and coping: A study of world class coaches. Journal of applied sport psychology, 22(3), 274-293.

Ostrom, E., (1990). Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, New York.

Ostrom, E., (2001). Social capital: a fad or a fundamental concept?. In: Serageldin, I., Dasgupta, P. (Eds.), Social Capital: a Multifaceted Perspective. World Bank, Washington D.C..

Ostrom, E., (2009). A general framework for analyzing sustainability of social– ecological systems. Science 325, 419–422.

Ostrom, E., Burger, J., Field, C.B., Norgaard R.B., & Policansky, D. (1999). Revisiting the Commons: Local Lessons, Global Challenges. Science 284, 278-282.

Paudyal , B.R., Neil, P., Allison,G., (2006). Experiences and challenges of promoting pro-poor and social inclusion initiatives in user group forestry. Journal of Forest and Livelihood 5, 34–44.

Peake, R. (1989). Swahili Stratification and Tourism in Malindi Old Town, Kenya. Africa, 59(2), 209-220.

Perch-Nielsen S, Sesartic A, Stucki M. 2010. The greenhouse gas intensity of the tourism sector: the case of Switzerland. Environmental Science and Policy 13: 131–140. DOI: 10.1016/j.envsci.2009.12.002

Polasky, S.,Nelson, E., Pennington, D. & Johnson, K.A. (2010). The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. Environmental and Resource Economics 48: 219–242.

Polman, N., Reinhard, S., van Bets, L. K., & Kuhlman, T. (2016). Governance of ecosystem services on small islands. Island Studies Journal, 11(1), 265-284.

Putnam et al., 1993). Putnam, R.D., Leonardi, R., Nanetti, R., (1993). Making Democracy Work: Civic Traditions in Modern Italy. Princeton University Press, Princeton, New Jersey.

Raudsepp-Hearne, C., Peterson, G.D., Tengo, M., Bennett, E.M., Holland, T., Benessaiah, K., MacDonald, G.K., Pfeifer, L., (2010). Untangling the environmentalist's paradox: why is human well-being increasing as ecosystem services degrade? BioScience 60, 576–589.

Raworth, K. (2012). A safe and just space for humanity: can we live within the doughnut. Oxfam Policy and Practice: Climate Change and Resilience, 8(1), 1-26. Ribot, J.C., Peluso, N.L., (2003). A Theory of access. Rural Sociology 68, 153–181.

Rodríguez, J.P., Beard, T.D., Bennett, E.M., Cumming, G.S., Cork, S ., Agard, J., Dobson, A.P., Peterson, G.D., (2006). Trade-offs across space, time, and ecosystem services. Ecology and Society 11,28.

Saaty, T. L. (1980). The analytical hierarchy process, planning, priority. Resource allocation. RWS publications, USA.

Scheyvens R. 2007. Exploring the tourism poverty nexus. Current Issues in Tourism 10: 231-254.

Scheyvens, R., & Momsen, J. H. (2008). Tourism and poverty reduction: Issues for small island states. Tourism Geographies, 10(1), 22-41

Schlager, Ostrom, E., (1992). Property rights regimes and natural resources: a conceptual analysis. Land Economics 68, 249–262.

Schleicher, J., Schaafsma, M., Burgess, N. D., Sandbrook, C., Danks, F., Cowie, C., & Vira, B. (2018). Poorer without it? The neglected role of the natural environment in poverty and wellbeing. Sustainable Development, 26(1), 83-98.

Scoones, I. (1998). Sustainable Rural Livelihoods: A Framework for Analysis. IDS Working Paper 72:1–22.

Scott D, Amelung B, Becken S, Ceron J-P, Dubois G, Gössling S, Peeters P, Simpson M. (2008). Technical report. In Climate Change and Tourism: Responding to Global Challenges. UNWTO: Madrid; UNEP: Paris; WMO: Geneva; 23–250.

Scott D, Peeters P, Gössling S. (2010). Can tourism deliver its 'aspirational' emission Reduction targets? Journal of Sustainable Tourism 18: 393–408. DOI: 10.1080/09669581003653542

Sen, A., (1981). Poverty and Famines: An Essay on Entitlement and Deprivation. Clarendon, Oxford.

Sen A. (1985). Well-being, agency and freedom: the Dewey lectures 1984. The journal of philosophy 82(4): 169-221.

Sen, A., (2001). Development as Freedom. Oxford University Press, Oxford.

Shang-Pao, Y. E. H., & Fotiadis, A. K. (2014). Social interactions in rural tourism: A host perspective case study. Revista de Cercetare Si Interventie Sociala, 46, 131.

Shaw G., Williams A.M, (1996). Critical issues in tourism. A geographical perspective. Blackwell Publishers Inc., Oxford – Cambridge, MA.

Shea, W. R. (1976). Introduction: the quest for a high quality of life', In (Eds.) Shea, W. R.,& King-Farlow J. Values and the Quality of Life (pp. 1–5). Science History Publications. New York.

Sheppard, E., Porter, P. W., Faust, D. R., & Nagar, R. (2009). A world of difference: Encountering and contesting development. Guilford Press.

Sikor, T., Nguyen, T.Q., (2007). Why May Forest devolution not benefit the rural poor? Forest entitlements in Vietnam's central highlands. World Development 35, 2010–2025.

Sirakaya, E., Teye, V., & Sönmez, S. (2002). Understanding residents' support for tourism
development in the central region of Ghana. Journal of travel research, 41(1), 57-67.

Stonich, S. (2003) The political ecology of Marine Protected Areas: the case of the Bay Islands, in: S. Gossling (Ed.) Tourism and Development in Tropical Islands: Political Ecology Perspectives, 121–147 (Cheltenham: Edward Elgar).

Suansri, P. (2003). Community Based Tourism Handbook. Bangkok: Responsible Ecological Social Tour (REST).

Suansri, P. (2005). Ecotourism: People Participation. Tourism for Life and Nature Project, Bangkok, 118.

Tallis, H., Kareiva, P., Marvier, M., & Chang, A. (2008). An ecosystem services framework to support both practical conservation and economic development. Proceedings of the National Academy of Sciences, 105(28), 9457-9464.

TEEB (2010) The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A Synthesis of the Approach, Conclusions and Recommendations of TEEB, Malta: Progress Press.

Thoms, C.A., (2008). Community control of resources and the challenge of improving local livelihoods: a critical examination of community forestry in Nepal. Geoforum 39,1452–1465.

Tosun, C. (2000). Limits to community participation in the tourism development process in developing countries. Tourism Management 21 (6): 613-633.

Tosun, C. (2001a). Challenges of sustainable tourism development process in the developing world: the case of Turkey. Tourism Management. 22(3), 285-299.

Tosun, C. (2001b). Host perception of impact: A comparative Tourism Study. Annals of Tourism Research. 29(1). 231-253.

Tosun, C. (2006). Expected level of community participation in the tourism development process. Tourism Management 27(1): 493-504.

Turner, R. K., & Daily, G. C. (2008). The ecosystem services framework and natural capital conservation. Environmental and Resource Economics, 39(1), 25-35.

Turpie, J. K., Marais, C., & Blignaut, J. N. (2008). The working for water programme: Evolution of a payments for ecosystem services mechanism that addresses both poverty and ecosystem service delivery in South Africa. Ecological economics, 65(4), 788-798.

Tuula H., & Tuuli H. (2015) Wellbeing and Sustainability: A Relational Approach. Sustainable Development 23, 167–175.

UNEP and WTO (2005). Making tourism more sustainable. A guide for policy makers. Paris and Madrid.

UNWTO & UNDP. (2017). Tourism and the Sustainable Development Goals – Journey to 2030. Madrid: UNWTO and UNDP.

Wallace, K. J. (2007). Classification of ecosystem services: problems and solutions. Biological conservation, 139(3-4), 235-246.

White S. (2009). Analysing wellbeing: A framework for development Practice. WeD Working Paper 09/44 .

Willemen, L., Verburg, P. H., Hein, L., & van Mensvoort, M. E. (2008). Spatial characterization of landscape functions. Landscape and urban planning, 88(1), 34-43.

Wilson, J. (1972). The industrial process and the quality of life. In (Eds.) Stober, G.J, & Schumacher, D. Technology Assessment and Quality of Life, Proceedings of the 4th General Conference of SAINT, Elsevier Scientific Publishing Company, Salzburg, Austria, 131–146

Wilson, G. A. (2004). The Australian Landcare movement: towards 'post- productivist' rural governance?. Journal of Rural Studies, 20(4), 461-484.

Wunder, S. (2008) Payments for environmental services and the poor: concepts and preliminary evidence. Environment and Development Economics 13: 279–297.

Wunder, S., (2007). The efficiency of payments for environmental services in tropical conservation. Conservation Biology 21,48–58.

Yen I, Kerstetter D. (2009). Tourism impacts, attitudes and behavioral intentions. Tourism Analysis 13(5-6): 545-564.

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **201-207**
http://dx.doi.org/**10.5775/fg.2022.054.d**

International migration and its impact on the spatial dynamics of Guercif city (Morocco)

Mohammed ELYAAGOUBI[1,*]

[1] Faculty of Arts and Humanities, Department of Geography, University of Sidi Mohamed Ben Abdellah, Sais, Fez, Morocco
* *Corresponding author*: medyagoubi12@gmail.com

Received on 21-04-2022, reviewed on 12-08-2022, accepted on 29-09-2022

Abstract

This study is based on the field survey, one methodological tool among others used mainly in the social sciences. The aim is to determine the impact of international migration on the spatial dynamics of the city of Guercif. A phase of reconnaissance of the field, followed by a qualitative stage marked by interviews with the respondents, allowed us to verify the results and exploit them quantitatively via questionnaire. The analysis of the responses from 230 valid questionnaires indicate a strong involvement of migrants from the city of Guercif in speculation and the animation of the land market, thanks to the funds transferred.

Keywords: *survey, international migration, spatial dynamics, questionnaires, land market*

Rezumat. Migrația internațională și impactul acesteia asupra dinamicii spațiale a orașului Guercif (Maroc)

Lucrarea de față se bazează pe un studiu de teren, o metodă deseori folosită în cadrul științelor sociale, cu scopul de a determina impactul migrației internaționale asupra dinamicii spațiale a orașului Guercif. După o etapă de familiarizare cu situația din teren, a urmat o etapă calitativă în care am desfășurat interviuri cu diverși respondenți care ne-au permis să verificăm rezultatele preliminare și să le valorificăm apoi din punct de vedere cantitativ prin intermediul unui chestionar. Analiza răspunsurilor obținute în cadrul a 230 de chestionare valide indică o implicare puternică a migranților din orașul Guercif în speculațiile și dinamizarea pieței imobiliare datorită infuziei de capital.

Cuvinte-cheie: *sondaj de opinie, migrație internațională, dinamici spațiale, chestionare, piața imobiliară*

Introduction

The phenomenon of migration is a global trend. Its multidisciplinary aspect puts it at the center of the concerns of various disciplinary fields such as economics, sociology, and above all geography, which has invested the most in this field because of its mobility and spatial aspect (Berriane.M and Aderghal.M, 2008). The report of the International Organization for Migration (IOM, 2019) on the state of migration in the world in 2020, estimates the share of migrants to be 3.5% of the world population. Morocco is considered an important basin of international migration, perceived among the capital dynamics of the population. Since the second half of the twentieth century, Morocco has been the point of departure for migrants to various destinations, particularly Western European countries. With the entry into force of the Schengen Agreement in 1990, it was illegal or clandestine emigration that fed the human flow from Morocco. In this regard, the city of Guercif, among others, was a rear base for illegal emigration networks and a transmitting center during the 1990s the latter in a perspective where ‹‹migrants exchange misery without hope for… misery with hope››. (Adepoju, 1988: 123). Unemployment and poverty have largely induced mass migration, which reveals the economic and social imbalance, and which turns after some time into mass migration since the migrant does not take long to bring his family as part of family reunion. The benefits and costs associated with migration are expressed in terms of economic gains that affect different aspects of the urban landscape of the city of Guercif, mainly the real estate sector which is a privileged investment area for local migrants.

Generally, the expansion of our cities is partly a consequence of the intervention of migrants in the revitalization of the construction sector; this is a finding confirmed by several studies that have focused on the phenomenon of urban expansion (Elaklaâ El Aklaâ et al, 2013). In this sense, international migration is captured as a driver for urban dynamics that have experienced in the case of the city of Guercif a revealed boom. The model of the migration cycle (OECD, 2007) allows us to attest to the consolidation phase in which our study area is, marked by the increase in remittances and the decrease in poverty. This article aims to show the impact of international migration on the spatial dynamics of Guercif on the one hand, and the role of local migrants in the animation of the land market and the production of housing on the other.

Study area

The city of Guercif, the capital of the province is located on a plain of the same name at 378 m above sea level. It is located in the North-East of Morocco at a crossroads between the corridor of Taourirt in the East and that of Taza in the West along with the national road No. 6 on the one hand, and between the North and the South-East along with the national road No. 15 on the other hand (Fig. 1); hence the status of relay city qualifying Guercif. This has given it a strategic geographical location at the center of a triangle whose vertices are Oujda, Nador, and Fez, cities of great importance in the national urban framework (Oujda, Nador, and Fez). It was created by the dismemberment of the province of Taza following the administrative division of 2009. Since 2015, Guercif is part of the Oriental region. The uniqueness of this city lies in the place it holds as a single city in a vast province (over 7300 km^2), consisting of nine other municipalities that are all rural. It is enclosed in the neighboring commune of Houara Oulad Rahu.

Historically, the countries of North Africa, and particularly Morocco have constituted an important basin of international migration. Indeed, towards the beginning of the 20th century, Morocco was the destination of European migrants within the framework of the colonial occupation; but with the beginning of the second half of the last century, it became the starting point for the flow of Moroccan migrants to western Europe, especially France, Belgium, Holland, Germany. Later, around the 90s of the last centuries, and with the entry into force of the Schengen agreements, the number of legal migrants fell considerably and it was illegal emigration that would arouse the interest of young candidates for emigration. In this regard, the contribution of the city of Guercif to international migration is relatively recent compared to other cities in the country, because it only began to gain momentum around the second half of the 90s of the last century. The enthusiasm for the phenomenon of migration at the local level set Guercif up as a rear base for illegal emigration networks until 2008 when the pace of emigration was slowed down due to global economic crisis and its impact on the labor market in Europe in general, and particularly in Spain, a preferred destination for young people of the city of Guercif. Despite this, the dream of reaching the "European El Dorado "has not ceased to seriously occupy the minds of the young people of the city and its margin. The security situation induced by the Arab spring revolutions in neighboring countries Tunisia and Libya has benefited networks active in the field of illegal emigration from Tunisian and Libyan coasts. During our field survey, several interviewees assured us that many young people from the city of Guercif took this mode of emigration, especially in 2016 and 2017.

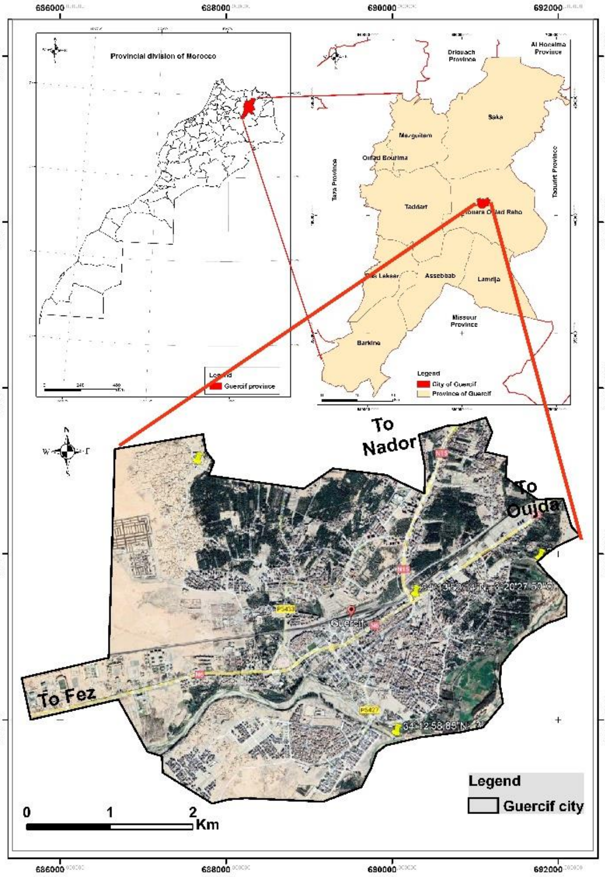


Fig. 1 Study area

Sources: Provincial division (2009), Urban plan of Guercif (2015), and Landsat 2019 satellite image of Guercif.

Moreover, the most significant urban development was recorded in Guercif at the beginning of the 1980s when the city became a center for commercial and service activities. The current urban perimeter is the result of a succession of administrative divisions, and the area of the city has grown from 500 ha to the current 1900 ha. From a demographic point of view, data from the general census of population and housing in Morocco show that the population of the city of Guercif has increased from 11340 inhabitants in 1982 to 90880 inhabitants in 2014. Current projections from the center for demographic studies and research (CDSR) and the high commission for planning (HCP) estimate the population of Guercif at 118674 inhabitants in 2021. This demographic boom has resulted in disproportionate urbanization in which migrants have massively participated in the production of housing in a regulatory framework and sometimes in a framework of self-urbanization thanks to the funds transferred.

It should be recalled that State intervention in the area of social housing has essentially benefited a small segment of the solvent population, while a large part of the population has been forced to opt for non-regulatory and low coast housing. Thus, towards the end of 2004, more than 59% of the city's population lived in substandard housing (AUT, 2008). The expansion of the city of Guercif is a consequence of the socio-economic and spatial evolution induced by several factors including international migration. The counting of building permits issued between 2000 and 2019 shows that 29% of beneficiaries are migrants. Hence, the role of income from international migration in the animation of the construction sector in the city of Guercif.

Methodology

To carry out this work, we first made an observation and a reconnaissance of the areas where the projects of the migrants who are the target of our survey are located, then we collected data using interviews with officials having a direct or indirect relationship with the issue of migration, such as the council for Moroccan nationals abroad, the ministry in charge of Moroccans residing abroad, the prefecture of Guercif (division of passports and immigration, economic and social division) the services of the municipality. Then, we draw up a questionnaire aiming to extract quantitative information on the investments of the migrants relating to the field of urbanizable land. The questions covered the subjects raised in the study in order to get the most representative idea possible of the phenomenon. The questionnaire targeted the heads of household and it covered various aspects of the migrant's situation before the first migration (age, place of birth, place of residence, activity carried out, monthly income, level of learning, reasons for immigration, year, type -legal or illegal- destination, date of regularization of the migrant's situation, activity, marital status, number of children, monthly income, frequency and volume of transfers, number of visits to the country of origin, type of habitat, status, mode of production, investments, etc. A corpus of work consisting of 230 questionnaires distributed proportionally to respondents during the summer of 2021, a period which coincides with a mass return of migrants, aims to collect information on the respondent's situation before and after migration: activity carried out, average monthly income, reason for immigration, age, year of migration, type of migration (legal/illegal), destination, activity, average monthly income abroad, the volume of transfers, type of investments. The investigations carried out in six areas of the urban perimeter (Fig. 2), enabled us to assess the involvement of local migrants in the urban sprawl experienced by the city of Guercif.

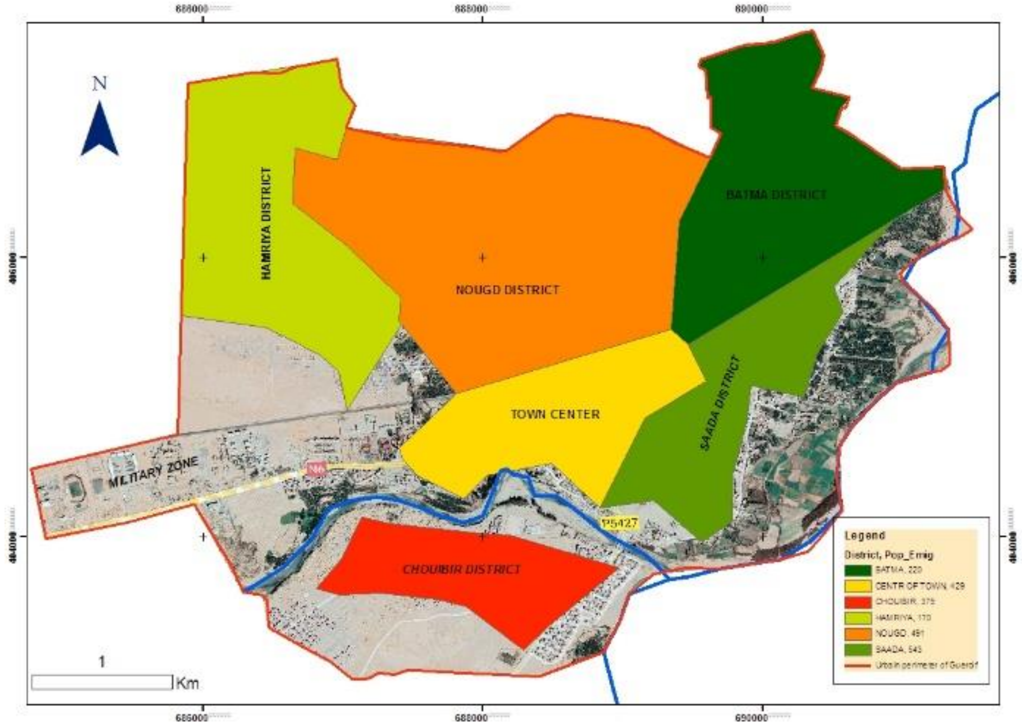


Fig. 2: Distribution of surveyed areas within the urban perimeter

Faced with the impossibility of making a complete search of the migrant in the city and given the irregularity of the period of their return, we resorted to a representative sampling where the respondents were selected according to the information collected from the "Moquaddam" , representative of the authority at the district level. The total population of each neighborhood surveyed is given by the general census of population and housing 2014 in Morocco, and the number of households per neighborhood was provided to us by the "Moquaddam".

Thus, a 10% sample of the emigrant population was the main source of data for this study (Table 1). The statistical unit being the household and the interviewee is the father whose age at the time of the first migration was between 20 and 40 years for 79.2% of the sample surveyed.

Table 1: Distribution of samples to be surveyed

Surveyed area/ district	Total population	Emigrant population	Sample to be surveyed
Town center	13627	509	51
Nougd	13258	491	49
Saâda	18473	543	54
Batma	5492	220	22
Chouibir	19356	379	37
Hamriya	18293	170	17

Source: General census of population and housing (2014) and representative of authority (2021)

In addition, to complete this work, we conducted a documentary analysis of the building permits issued by the competent services in the municipality of Guercif. Sorting of the database related to the authorized constructions allowed us to attest to the role of migrants in the dynamization of the building sector in Guercif.

To get an idea of the weight of migrant investments, an analysis grid was developed from the questionnaire to retain the essential information relating to the contribution of migrants to the spatial dynamics of our study area. The information retained concerns:

1- The investments of the migrants (urbanizable land, area, location, use).

2- The method of financing (self-financing, self-financing + bank credit, self-financing + family credit)

3- Increase in the flow of migrants to Europe and its consequences on the land market

To facilitate the analysis and synthesis process, the information collected was captured and processed to present the main aspects of the study based on the survey data.

Results and discussions

Land investment: a priority for migrants

The impact of migration on the sprawl of the city of Guercif is the priority aspect of this study. The result of our survey showed the prevalence of the land sector which represents a share of 78,90% of all investments by migrants in Guercif. The field survey carried out on the occasion of the completion of thesis work in 2019 on the urban growth of the city of Guercif testifies to the real estate self-promotion of migrants and reveals that most of the investments are directed towards real estate which occupies an 80% share among the overall investments migrants. These investments are mostly located in the city of Guercif, which monopolizes 95% of the real estate project carried out, hence a significant contribution to urbanization and consequently the sprawl of the city. The remaining share is spread over other cities such as Taza, Fez and Oujda. These results are supported by the work of Hamdouch (Hamdouch B et al, 2000) which showed that the share of real estate in the investment of migrants is around 83,7%; as well as those of the high commission for planning survey in 2005 which showed that the real estate sector represented 86.9% of all investments by Moroccan migrants. In addition, the total remittances from emigrants represent 7 to 8% of the Moroccan gross domestic product (GDP), of which 10% are intended for investment in general and real estate monopolize 70% of the volume dedicated to investment (Migraion & Developpement, 2014).

These investments cover the entire chain of housing from the purchase of land to construction. The study revealed that 14.8% of the migrants surveyed owned built assets (house, building); 31.6% owned lots in regulatory housing estate, and 1.2% of migrants were developers. The plots, whose total number was 117, were distributed over the area surveyed (Table 2) and their surface varies according to the sector.

Table 2: Distribution of batches of migrants by sector

Surveyed area	Number of batches
Town center	9
Nougd district	37
Saâda district	22
Batma district	30
Chouibir district	9
Hamriya district	10

The Nougd and Batma districts monopolize more than 57% of the lots. These initially agricultural lands are more coveted by migrants for their incentive prices. The number of lots per district (mainly Nougd and Saâda) goes in hand with the number of migrants which are spread over European countries with variable frequencies between districts depending on the host country (Fig. 3). It should be noted that Spain is home to the majority of migrants in the town of Guercif.

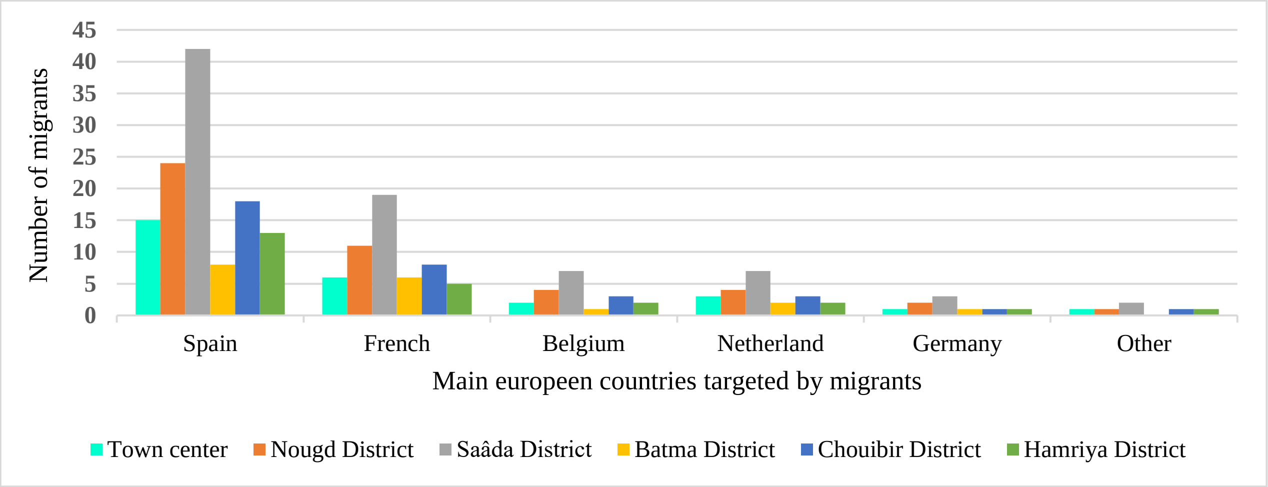


Fig. 3: Distribution of the number of migrants by district and by host country

Migrants in the city of Guercif mainly come from Nougd and Saâda districts. The lots in these districts have an area that varies from 84 to 120 m2 for 71.79% of the lots; this is the ideal area for a modern Moroccan house reserved for housing and the practice of commercial activity on the premises on the ground floor. The remaining lots have an area ranging from 121 and 600 m2 are generally dedicated to the construction of building with some exceptions concerning the construction of villas for the personal use of the migrant, or the fragmentation to build or sell (Fig. 4).

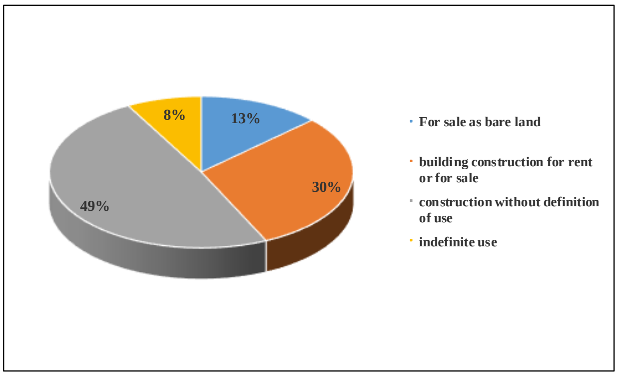


Fig. 4 Subsequent use of the land aquired by the migrants of Guercif

Due to the guaranteed benefits it provides, access to land ownership has became a means for migrants in the city of Guercif to diversify their sources of income. Thus, 43% of respondents intend to sell or rent their real estate. This observation is supported by Mansour Tall (Tall, 2009) who specifies that generally, in the countries of the south, "Emigrations are driven by a strong desire to access property ownership. The stakes of this craze lie in the fact that the realization of a construction can be profitable by leasing or speculation".

Thus, a significant part of the migrants' land holdings, 79%, is destined for housing production, which shows the weight of the migrants' contributions and their consequences on the sprawl of the city of Guercif. The rental market is of most interest to the migrant who ensures a permanent monthly income and prefers not to sell the property (Fig. 5). Indeed, 50% of the sample surveyed indicated that their real estate investment is intended exclusively for the rental market, while a significant proportion of the respondents still hesitates about the use reserved for the buildings that have been built and are still empty.

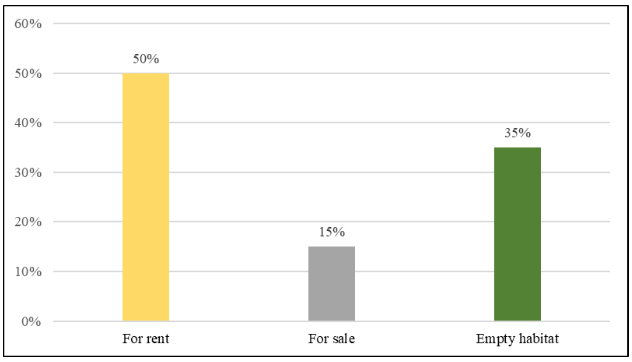


Fig. 5: Uses of the housing stock by the migrants of Guercif

Since the promotion of the city of Guercif into a provincial capital and the massive installation of various government services, demand in the rental market has increased due to the needs of newcomers represented by government officials. This partly explains the tendency of migrants to rent rather than sell.

Self-financing as a mode of housing production

Concerning the method of financing the real estate investments of the migrants in our study area, we noted a clear pre-eminence of self-financing, the recourse to credits from banking institutions being very limited.

The tiny share of credits granted by banks to real estate investments by migrants in the city of Guercif is explained by the complexity of administrative procedures. Indeed, the absence of a mortgage to secure the loans is a deterrent for the bank to engage with the migrant in such projects. In addition to this, the very high-interest rate set by the banking institutions; hence the recourse to the migrant's means as the ultimate means of financing his real estate projects.

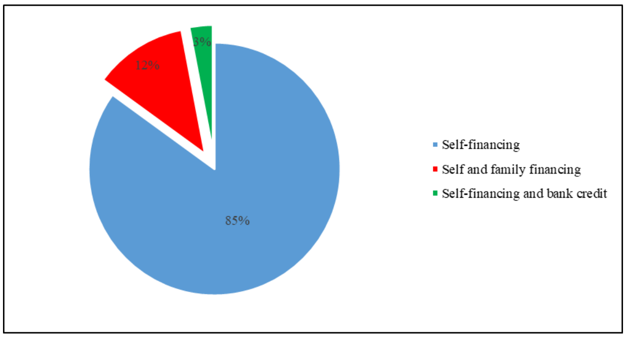


Fig. 6: Method of financing real estate investments of migrants in Guercif

In addition, the contribution of migrants to the dynamics of the construction sector in Guercif is illustrated through the evolution of the number of building permits that have experienced a sustained increase, especially since the promotion of the city to the provincial capital in 2009.

Table 3: Evolution of the number of building permits

Period	1992-2002	2003-2009	2010-2019
No. of building permits	3000	2213	5819

Source: Municipality of Guercif - urban planning department (2019)

In this regard, a review of all permits granted during the period 2010-2019, we concluded that 25% of permits are in the names of migrants in the city, hence the important role of this social fringe as a promoter of the development dynamics of urbanization and growth of the city. The area of land subject to building permits varies from 84 square meters in regulatory housing estates to 600 square meters (Fig. 7) in non-regulatory housing estates where speculation is driven by incentive prices.

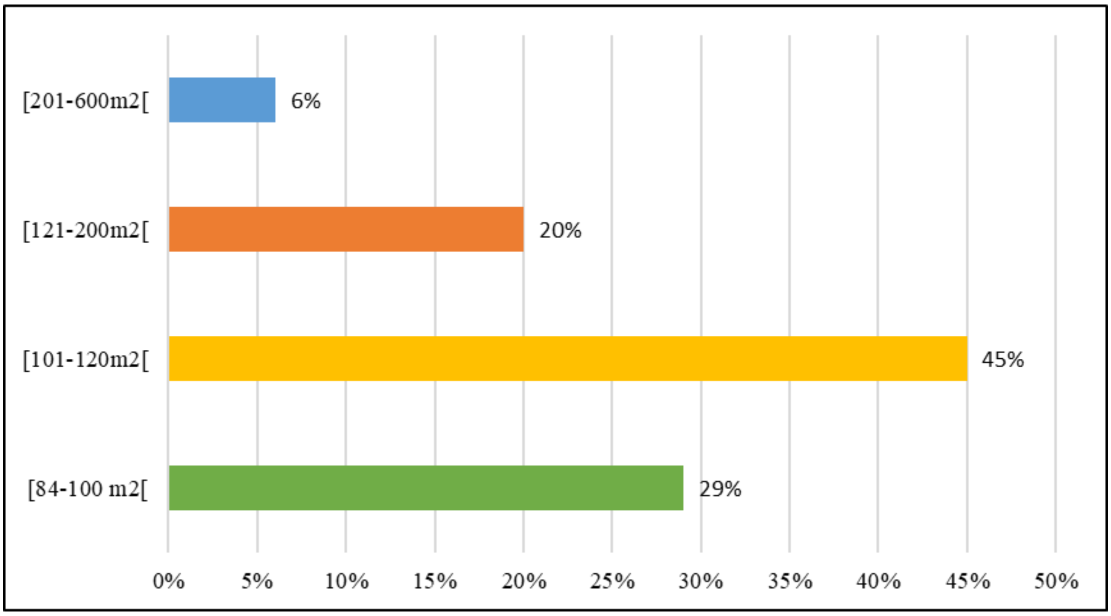


Fig. 7: Surface area of Guercif migrant plots

In addition, and parallel to the increase in the flow of migrants from the city of Guercif to Europe, a surge in prices was recorded in the land market as a result of the growing demand and the monopoly of migrants, especially after 1995. It should be noted that real estate speculation only appeared with the introduction of the capitalist mode of production that succeeded the traditional legal, economic and ideological modes of relations of pre-capitalist property, and even the economic and social content of housing, which makes its field of production a sector of capital accumulation (. Saad, 1980). With the funds transferred, the migrant can finance the purchase of one or more lots, which he or she sometimes leaves as a reserve until good investment opportunities arise. This practice was observed among 8% of the migrants surveyed (Fig. 1). For cultural reasons, each African migrant in Europe could potentially buy two or three houses in his or her country of origin over 10 to 20 years [Smith, Mazzucato, 2009]. Indeed, the investment of migrant from the city of Guercif in a house is not only an economic act, but also a cultural and social issue. Before starting the investments, the migrant is first required to provide for the housing needs of his family who remind in the country. The construction of a house is an investment with a symbolic value which attests to the success of the migrant and his social advancement. The house expresses belonging to the city and is the place for family ceremonies. The more the migrants invests in this sector, the more he acquires social notoriety. Land investment is a guaranteed gain in a context marked by speculation and increase demand on housing.

Conclusion

The results of this study attest to the impact of migration on the dynamics of the construction sector and consequently the expansion of the city of Guercif by migrants. Most of their investments are directed towards real estate (80% of total investments), and the production of housing intended for the rental market is the reason for these investments. The migrant's land, the use of which is not specified, is a factor that fuels speculation and the increase in the price of urbanizable land. The migrant resorts to his financial means ensured by the income from his work in the host country to finance his real estate projects.

However, despite the investments of migrants from the city of Guercif,, the rush of banking establishments, the number of which increased from 8 to 17 between 2000 and 2021, towards the collection of funds from migrants and their reuse in region renowned for their dynamic economy, limits the prospects for economic growth in the city of Guercif.

Funding

This research received no external funding.

Acknowledgements

We thank the people we interviewed and who honestly answered our questions.

Conflicts of Interest

The author declare no conflict of interest.

References

Adepoju, A. (1988). Migration and urbanization in Africa. Problems and policies, in *The state of African demography*. IUSSP 123p

Agence urbaine de Taza (AUT). (2008). Projet de ville de Guercif : diagnostic prospectif. Taza.

Agénor, P. R., K. El Aynaoui (2003). Politiques du marché du travail et chômage au Maroc: une analyse quantitative. Washington, World Bank

El Aklaâ Mohamed et al (2013). Role of international immigration in the dynamization of urban spaces: case of the city of Kelât Essraghna, *Revue géographie du Maroc,* Tome 28, n° 1-2, pp 7-19

Hamdouch B et al (2000). Moroccans residing abroad, a socio-economic survey, INSEA, Rabat, p: 195-196

Lothar, S., Valentina, M. (2009). Constructing Homes, Building Relationships: Migrant Investments in Houses. *Tijdschrift voor Economische en Sociale Geografie*, vol. 100, no. 5, pp. 662-673

Berriane, M., Aderghal, M. (2008). State of research on international migration from, to, and through Morocco, Faculty of Letters and Human Sciences – Rabat, Country Paper: Morocco 2008

El Aklaâ. M., and al (2013). Role of international immigration in the dynamization of urban spaces: case of the city of Kelât Essraghna, Revue géographie du Maroc, Tome 28, n° 1-2, pp 7-19

Hamdouch, B., and al (2000). Moroccans residing abroad, a socio-economic survey, INSEA, Rabat, p: 195-196

International Organization for Migration (IOM), (2019). State of world migration 2020. IOM, Geneva.

Lothar, S., Valentina, M. (2009). Constructing Homes, Building Relationships: Migrant Investments in Houses. Tijdschrift voor Economische en Sociale Geografie, vol. 100, no. 5, pp. 662-673

OECD (2007). Policy Coherence for Development: Migration and Developing Countries, Paris, Organization for Economic Co-operation and Development. Perspectives on migrations and development n°1 - January 2014 "PRODUCTIVE INVESTMENT OF MOROCCAN RESIDENTS ABROAD AND DEVELOPMENT OF TERRITORIES", Editions Migrations & Développement

Saad, B, (1980). La formation du capital dans le bâtiment et travaux publics. *Bulletin économique et social du Maroc* (BESM), 141 :142

Tall, S. M. (2009). Investir dans la ville africaine, les émigrés et l'habitat à Dakar. Paris : Karthala.

Serine, MT. (2009). Investing in the African city, Emigrants, and housing in Dakar, KARTHALA, Paris

FORUM GEOGRAFIC

Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume **XXI**, Issue **2** (**December** 2022), pp. **208-225**
http://dx.doi.org/**10.5775/fg.2022.044.d**

The relationship between net migration and financial inclusion in Romania

Stefan JOHNSON[1*]

[1] Faculty of Science, Department of Demography and Geodemography, Charles University, Prague, Czechia
* *Corresponding author*: stefan.johnson@natur.cuni.cz

Received on 20-07-2022, reviewed on 07-10-2022, accepted on 02-12-2022

Abstract

Romania has been going through a unique demographic transition resulting in depopulation, partially due to consistently high emigration and low immigration rates. The population leaving has been predominantly those of working age. At the same time, Romania has also seen a stagnated financial inclusion growth rate between 2011 and 2017. This research explores the relationship between the age-group-specific net migration rates and age-group-specific financial inclusion rates provided by Findex. These age groups, which have a significantly strong relationship between net migration and financial inclusion, illustrate the impact of migration on financial inclusion rates. Age groups 25-29, 35-39, 40-44, and 45-49 have shown significantly strong inverse correlations between net migration and financial inclusion.

Keywords: *Romania, depopulation, migration, financial inclusion, demography, remittances*

Rezumat. Relația dintre migrația netă și incluziunea financiară în România

România a experimentat o tranziție demografică unică, ce a avut ca rezultat o depopulare considerabilă, în mare parte datorită unei rate mari de emigrare și o rată mică de imigrare. Cei care au plecat au fost in principal în vârstă de muncă. In același timp, rata de creștere a incluziunii financiare a stagnat în perioada 2011-2017. Această lucrare explorează relația dintre ratele de migrație pe grupede vârstă și ratele de incluziune financiară caracteristice grupelor de vârstă furnizate de către Findex. Aceste grupe de vârstă, care sunt într-o relație foarte strânsă cu migrația netă și incluziunea financiară, ilustrează impactul migrației asupra ratelor de incluziune financiară. Pentru grupele de vârstă 25-29, 35-39, 40-44 și 45-49 au fost stabilite cele mai mari corelații inverse între migrația netă și incluziunea financiară.

Cuvinte-cheie: *România, depopulare, migrație, incluziune financiară, demografie, remitențe*

Introduction

Financial Inclusion is a crucial topic and has origins as early as 1950 (Basix & Ramola, 1996). The topic area was brought to mainstream attention through dialogue about the importance in the discussion of economic development globally (Mohan, 1996), and gained momentum in the early 2000s (Girard, 2021). The world bank has defined this area of research as providing ways for individuals and businesses to access valuable and affordable banking products (Allen, Klapper, & Martinez Peria, 2016). The importance of financial inclusion has been associated with the development of excluded and marginalized populations, such as women and the poor in developing nations (Ozili, 2020; Cabeza-Garcia, Brio, & Oscanoa-Victorio, 2019; Tarsem, 2018). Financial inclusion is a crucial contributing factor to economic development in the EU - significantly more important in low-income countries in the EU (Huang, Kale, Paramati, & Taghizadeh-Hesary, 2021; Danisman, 2020; Pham, Nguyan, & Ngo, 2022).

In 2011, the first large-scale World Bank study was published regarding financial inclusion, called the Findex - the financial inclusion index. The purpose of the study is to track financial inclusion rate changes around the world triennially (Demirguc-Kunt A., Klapper, Singer, & Oudheusden, The Global Findex Database 2014- Measuring Financial Inclusion around the World, 2015). The study was funded by the Bill and Melinda Gates Foundation, administered by Gallup Inc., and sponsored by the World Bank (Demirguc-Kunt & Klapper, 2013). This triennial survey provides insight into the financial inclusivity in over 140 countries globally, with samples of 1,000 respondents per country, weighted to represent the country's demographic and socioeconomic landscape to correct for unequal sampling probability (World Bank, 2021). Since 2011, the inclusion rates have seen a net positive trend, with nearly all countries experiencing increased financial inclusion (Demirgüç-Kunt, 2018). However, Romania, a former communist country in Southeast Europe, is a unique case by global standards, as it has experienced positive and subsequent negative changes since 2011 (Demirgüç-Kunt, 2018).

Romanian inclusivity trends varied over the three Findex reported years – 45%, 61%, and 58% in 2011, 2014, and 2017 respectively (Demirgüç-Kunt, 2018). In contrast to Romania, the European Area has had an increased and stabilized financial inclusion rate in the three studies– 90%, 95%, and 95%, in 2011, 2014, and 2017, respectively. Moreover, the European and Central Asian regions have seen a positive trend – 45%, 58%, and 65% in 2011, 2014, and 2017, respectively (Demirguc-Kunt & Klapper, Measuring Financial Inclusion: The Global Findex Database, 2012; Demirguc-Kunt A., Klapper, Singer, & Oudheusden, The Global Findex Database 2014: Measuring Financial Inclusion around the World, 2014; Demirgüç-Kunt, 2018). Compared to other Balkan and Southeast European nations, Greece and Serbia have had similar inclusion trends to Romania. Similarly, all three countries - Romania, Greece, and Serbia - show familiar net migration trends (World Bank Group, 2021; World Bank Group, 2021; World Bank Group, 2021). Romania is ranked 16th in outbound migration globally and has had approximately 3.5 million outbound migrants since 2007. Moreover, it is the only country within the Balkans to be included in the top 20 list of highest emigration rates by country (Goga, 2020). Sandu (2012) provides context to the movement outward from the country, as it is generally seen as positive by most of the Romanian population to emigrate (Sandu, 2012). Moreover, Sandu (2012) provides context regarding the importance of returning migrants who bring back the skills developed abroad.

As a European Union member state, Romanian citizens can search within the EU for jobs without applying for work visas, which has impacted Romania's ability to keep well-trained workers within its borders (Goga & Ilie, 2017). Much of this phenomenon began occurring at a greater rate upon accession to the European Union and has been highly impactful on the economy (Botezat & Moraru, 2020; Gavriloaia, 2020). In an example provided by Goga & Ilie (2017), doctors are some of the most common skilled workers to leave the country due to the opportunity to earn more in other European Union member countries (Botezat & Moraru, 2020; Goga & Ilie, 2017). These migrants usually represent some of the most expensive trained employees and the most important human capital (Goga, 2020; Goga & Ilie, 2017). Most seek migration toward well-developed nations, including the United States, Great Britain, Germany, and France (Alexe, et al., 2011; Botezat & Moraru, 2020). Migration, however, is not limited only to the most well-trained employees in the country.

A survey in 2013 of 256 Romanians indicated that only 42.1% of individuals would not consider migration, while 39.9% of the Romanians surveyed indicated a high probability of migrating (Nae, 2013). The most common reason for leaving Romania was that respondents could not find a job, with pay being the second most prominent reason for leaving their homes. The most preventative reasons for emigration were an inability to find work abroad and labor discrimination abroad (Nae, 2013). Moreover, the age groups with the highest tertiary education attainment in 2010 were 25-34 and 35-44, with 20.6% and 13.4%, respectively (Nae, 2013).

This research will examine the relationship between age-group-specific net migration and the level of financial inclusion by age groups in Romania in the select years of 2011, 2014, and 2017. Mid-year age-group specific financial inclusion rates will be analyzed against mid-year age-group specific migration rates using Pearson r correlation coefficients. As asserted by Goga & Ilie (2017), migration is a factor associated with employment and pay and will represent the independent factor of analysis. Financial inclusion will be the dependent variable, as this will explore the relationship between the migration rates of mid-year age groups and net migration of mid-year age groups. According to Goga (2017) and Goga & Ilie (2020), high paying countries have lured many of the most well educated in the country to the West. If the impact of migration has been significant to those who seek work elsewhere, the country's total number of financial accounts is predicted to decrease. Financial Inclusion will also be correlated with age-specific education level rates and age-specific income quantiles to provide further evidence that there is a potential link between migration and financial inclusion.

Literature Review

Migration

Considerable research has been conducted regarding outward migration from Romania, as the problem has raised concern regarding the long-term impact of a depopulation (Otovescu & Otovescu, 2019). Goga & Ilie (2020) discussed the emigration issues associated with high reliance on remittance and the role that Brain Drain plays in the social structure of Romania. Many migrants between 1990 and 2006 moved as low-skilled workers with less education; however, a current problem is that many outbound migrants are high-skilled workers, such as doctors (Otovescu & Otovescu, 2019; Botezat & Moraru, 2020; Gavriloaia, 2020). Botezat & Moraru (2020), using historical data, found that the total number of physicians leaving Romania reached peak between 2007 and 2012 – including 1,160 physicians migrating to France in 2009 alone. This data may not represent the total number of physicians leaving the country; rather, it represents the host countries' records of registered doctor; therefore, the total number of physicians leaving the country is not entirely known (Botezat & Moraru, 2020). Enache & Gonzalez Rabanal (2018) estimate that, as of 2018, there were 15,700 Romanian doctors, 15,000 researchers, and many IT workers living abroad. Of 496 medical professionals who left Romania for opportunities in other European countries, 78.4%

responded that they left due to salary purposes – none of the respondents were satisfied with the salaries in Romania, and equally as problematic is that none of the respondents would go back to Romania (Popescu, Georgina Picu, & Popescu, 2018).

Goga & Ilie (2020) discussed the impact of emigration on Romania - the 16th highest ranking country in terms of diaspora globally. Furthermore, Goga (2017) emphasized the long-term impact of emigration on the GDP, mentioning that it is more than just problematic for the loss of low-skilled workers – as it was until 2007, but now resulting in the loss of many high-skilled workers. Not only is this affecting the income quantiles and the nominal GDP in the short run, but an equally pressing matter is the lower-level health care professionals' availability (Kuhlenkasper & Steinhardt, 2017; Popescu, Georgina Picu, & Popescu, 2018). Kuhlenkasper and Steinhardt (2017) provide more data regarding the movement of high skilled populations from developing to more developed regions. They indicate that many of those who own bank accounts are those who are high-skilled.

Building on the Harris-Todaro model (Harris & Todaro, 1970), Borjas and Bronars (1996) discuss families' decision-making when deciding to migrate. In many cases, the level of skill and availability of work and earning are influential factors when determining whether to leave for other opportunities and whether expectations of the destination were met. This is further corroborated by the study conducted by Gherhes, Dragomir & Cernicova-Buca (2020) which found that that 63.5% of Romanian engineering students would be leaving the country to pursue high-paying opportunities. 9.4% of the respondents stated that they are interested in migrating in order to obtain roles with better working conditions elsewhere. Only 4.6% of the respondents from the Gherhes, Dragomir & Cernicova-Buca (2020) study indicated that they would be leaving because there were not enough opportunities in Romania. Todaro & Smith (2015) indicate that low wages will drive individuals to migrate internationally or to urban areas.

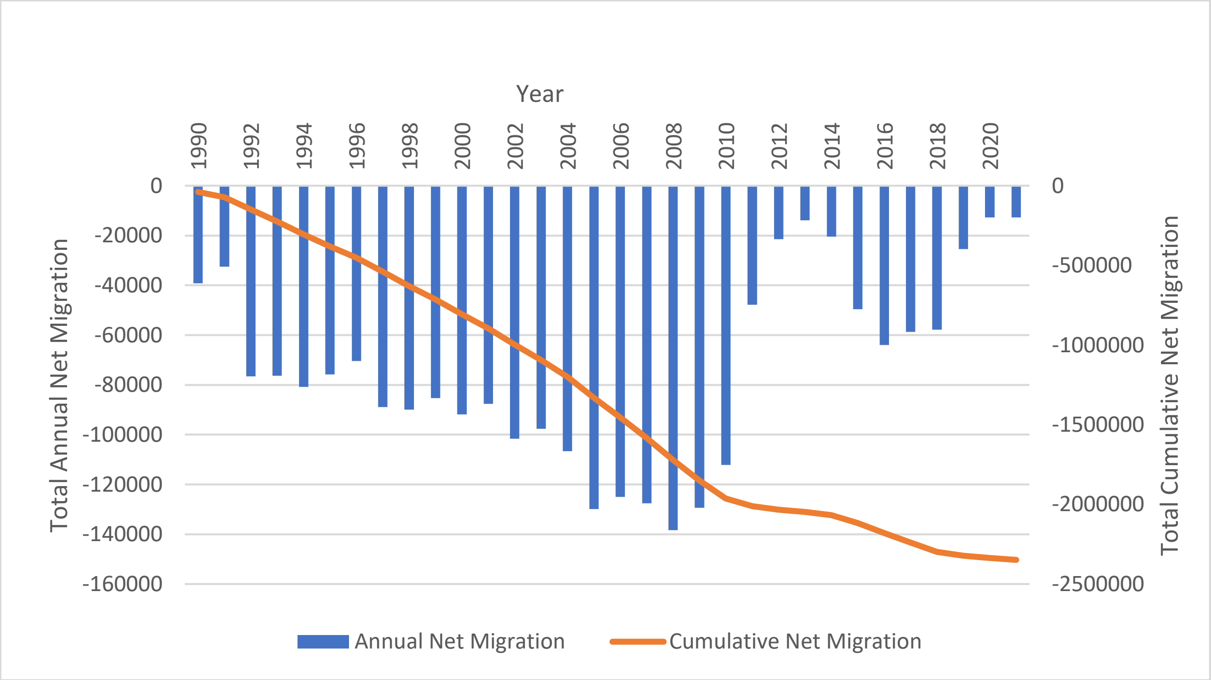


Fig. 1: Annual and Cumulative Net Migration, Romania, 1990-2021 (Data Source: United Nations Population Projection, 2022)

Migration remains a strong contributor to the population-related issues in Romania. This is especially true of the populations under 50 years old. As recently as 2017, Romania faced a net migration of -58,865, considering only the emigration and immigration of temporary migrants (United Nations, Department of Economic and Social Affairs, Population Division, 2022). Between 1990 and 2021, Romania has had a net migration total of -2,348,296, observing all types of migration.

Financial Inclusion

The World Bank definition of financial inclusion is, "individuals and businesses have access to useful and affordable financial products and services that meet their needs – transactions, payments, savings, credit, and insurance – delivered in a responsible and sustainable way" (World Bank Group, 2021; Chakrabarty, 2011). There is evidence that financial inclusion and development move closely with each other, and as early as 2011, using the Index of Financial Inclusion introduced by Sarma (2008), Sarma & Pais (2011) found that there is a strong correlation between per capita GDP and financial inclusion. In subsequent studies, it has been further discovered that as countries continue to reduce financial exclusion, females become more included in the financial system, infrastructure and human capital investments tend to increase, and the GDP tends to rise (Demirguc-Kunt & Klapper, 2013; Demirguc-Kunt A. , Klapper, Singer, & Oudheusden, 2014; Demirgüç-Kunt, 2018).

According to Al-Nimri and Al Nuaimi (2020), financial inclusion determinants for Romania are non-linear based on age and have an inverse relationship - older individuals in Romania tend to be without accounts. Moreover, this research corroborates the findings from Goga (2017), where individuals with higher levels of education tended to be more included in the financial system in 2014 compared to other years. Individuals with little money in Romania do not feel the need to open accounts (Altarawneh, Al-Nimri, & Al-Nuaimi, 2020). In the same study, it was found that education tends to remain the most significant obstacle for Romanians. Goga's (2017) research explains that the pay associated with high-skilled jobs such as Doctors is far less than other European counterparts and has contributed to brain drain. Similar data was found that 55% of engineering respondents would possibly or likely migrate permanently, and 57.9% of respondents suggested that they would possibly move abroad temporarily for work. The second highest response for reasons to leave Romania, after hard to find a job, was the level of income in Romania (Nae, 2013).

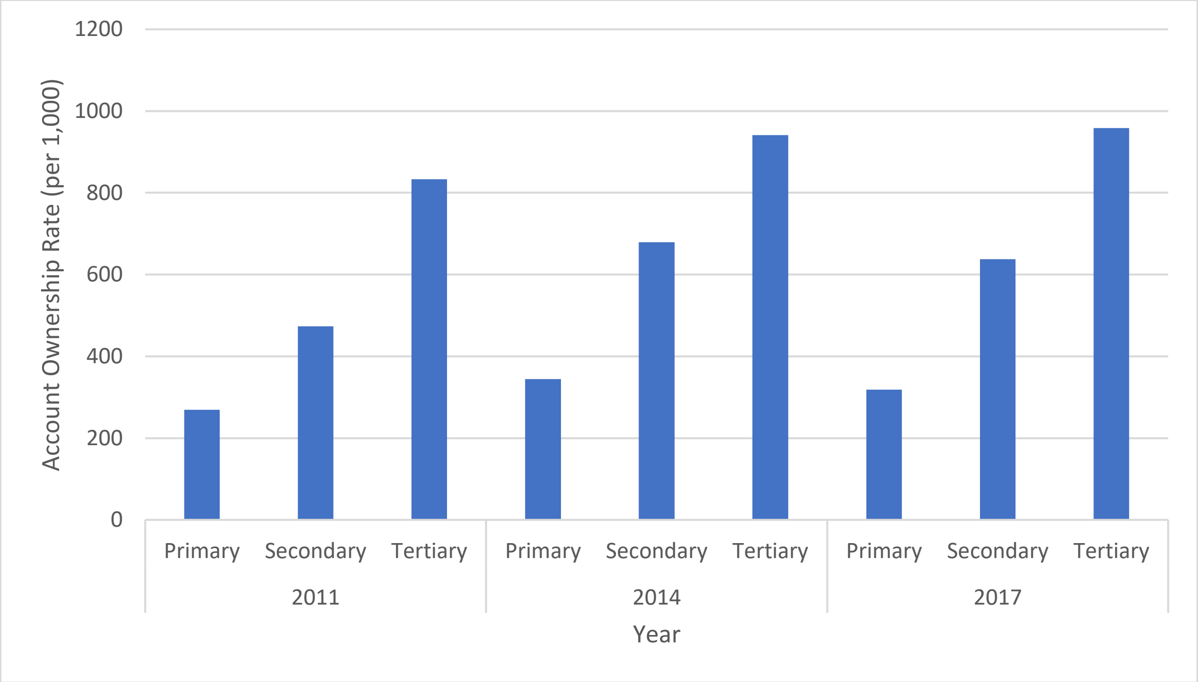


Fig. 2: Financial Inclusion Rates by Level of Education per 1,000, Romania, 2011-2017 (Data Source: World Bank Findex 2011, 2014, 2017)

As can be observed in Figure 2, the most significant financially included population are those who are trained to a secondary level. In contrast, as expected, those with the least education are those who are also the least financially included. Moreover, the movement in inclusiveness for these variables appear to be very similar to the overall Financial Inclusion rates. A Pearson r correlation coefficient will be calculated by age group and education level in order to understand the relationship between migration and education-level age-specific financial inclusion in Romania.

Income quantiles indicate 20-percentile units of the population that hold a proportion of the total wealth. This is an indicator of the amount of wealth a given 20% of the population holds – broken up into the poorest 20%, the second-poorest 20%, the third 20%, the fourth 20%, and the richest 20% - each quantile holds a total percentage of income. A typical method of identifying disparity between the richest and poorest in a country is observing the S80/S20, which works as a ratio between the top quantile and the bottom quantile – identifying how much the wealthiest have per 1 unit of the poorest (Popescu A., 2022). In observing the income quantiles and financial inclusion, the results are quite clear – Figure 3 illustrates that a higher income quantile means a higher probability of financial inclusion. This will be the final factor compared to migration.

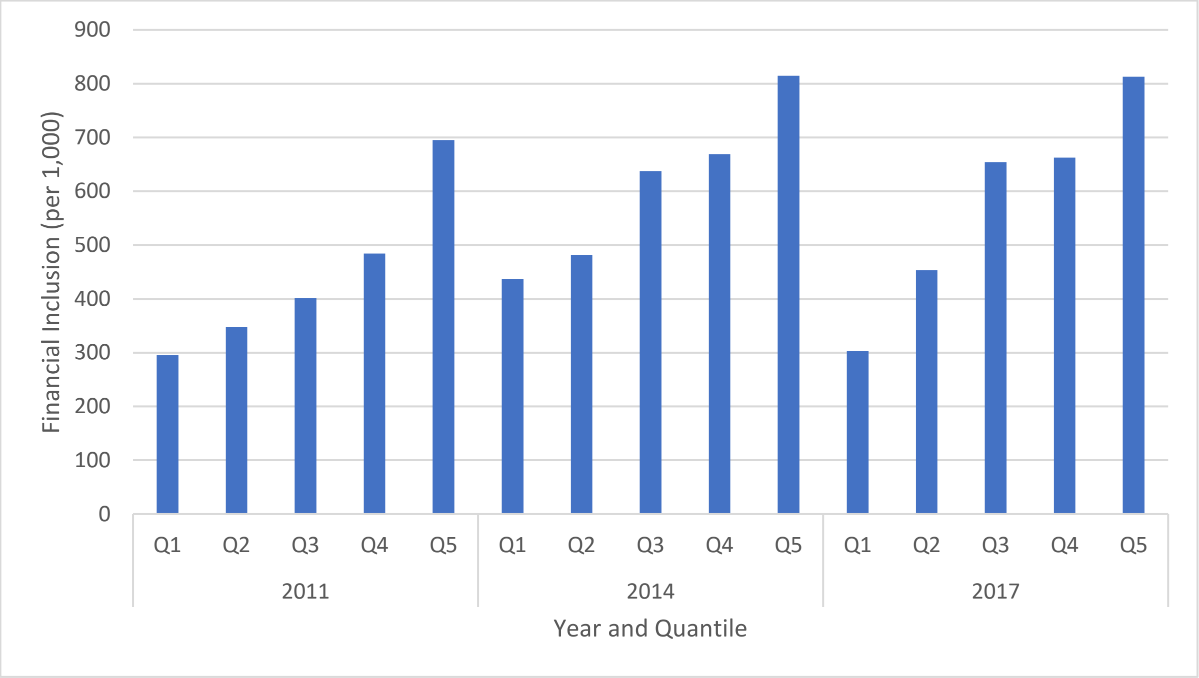


Fig. 3: Financial Inclusion by Income Quantile, Romania, 20112017 (Data Source: World Bank Findex, 2011, 2014, 2017)

A significant finding from the Findex was that in 2017, 23.7% of respondents who did not have an account stated that it was because banks are too expensive. In addition, 25.8% of respondents did not have an account because of a lack of trust in the banks or government (Demirgüç-Kunt, 2018). In 2014, these findings were 9.3% and 31.5% respectively (Demirguc-Kunt A., Klapper, Singer, & Oudheusden, The Global Findex Database 2014: Measuring Financial Inclusion around the World, 2014), meaning that the cost constraint became larger, but the trust in government became less of an issue. Generally, the largest constraint in each survey year, as seen in Figure 4, is that there was a lack of money to put into accounts – in 2017 58% of respondents indicating this as the case, down 10% from 2011.

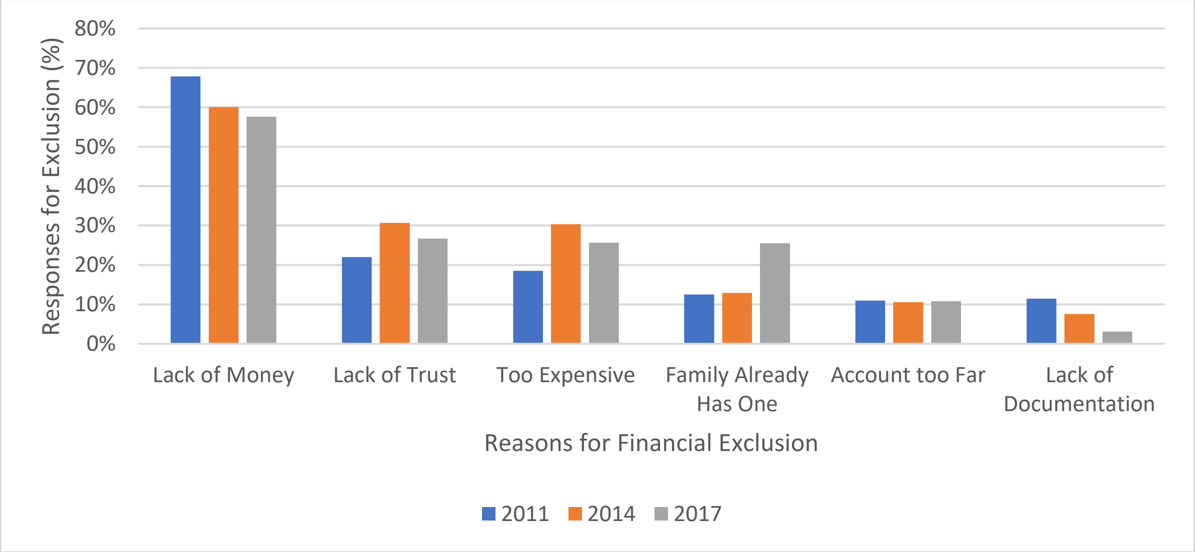


Fig. 4: Reasons for Financial Exclusion, Romania, 2011-2017 (Data Source: World Bank Findex, 2018)

Romania is on par with the rest of the EU by per capita bank branches and ATMs – 28 branches per 100,000 adults and 68 ATMs per 100,000 adults. This is slightly above the EU average of 25 and 63, respectively (World Bank, 2020). The disparities between rural and urban Romania, however, are quite vast - only 14% of the total branch networks are in rural Romania – 8 per 100,000 adults (World Bank, 2020). This disparity might also provide insight into why wealthier and more educated people own bank accounts – there is more wealth is in urban centers, where there may be more career opportunities. Thid can be corroborated through data from Eurostat as GDP by region. Figure 2 illustrates the disparity between Bucharest and the rest of the regions in Romania in GDP. Additionally, Figure 3 provides context for total deposits by county. Not only by GDP, but also by total personal deposits, Bucharest is the highest earning region in Romania. Beyond the GDP and the deposits, Bucharest also had the highest personal deposits per capita in all of Romania in 2017, as seen in Figure 4.

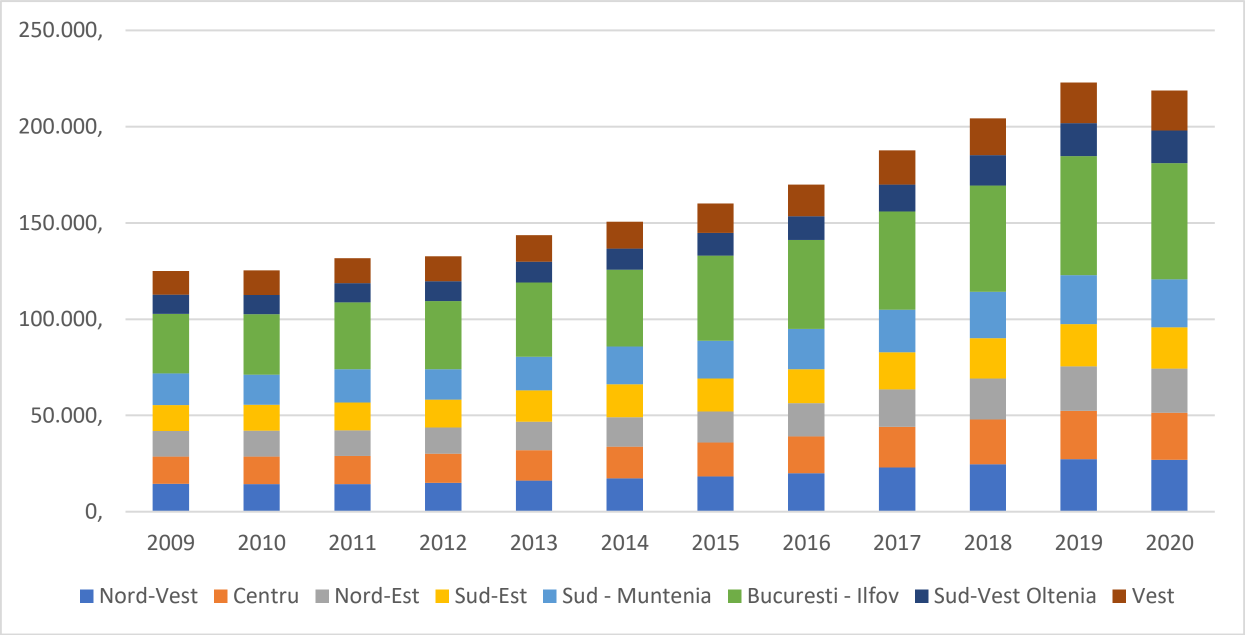


Fig. 5: GDP by Region, Romania, 2009-2020 (Data Source: Eurostat, 2023)

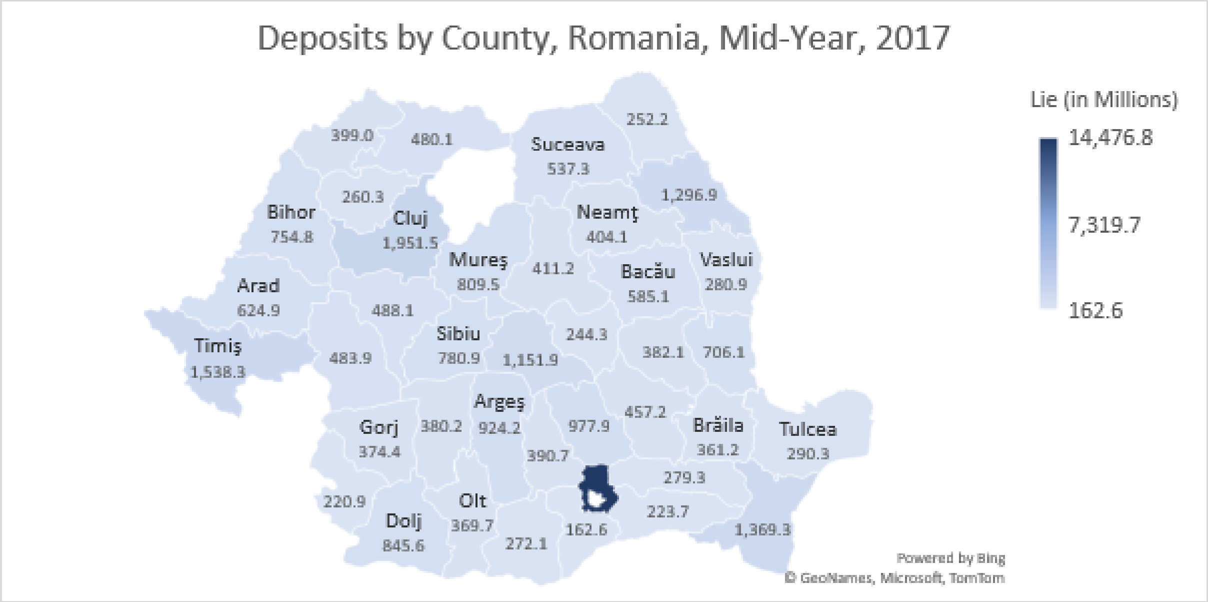


Fig. 6: Deposits in Personal Bank Accounts by County, Romania, 2017 (Data Source: National Bank of Romania, 2023)

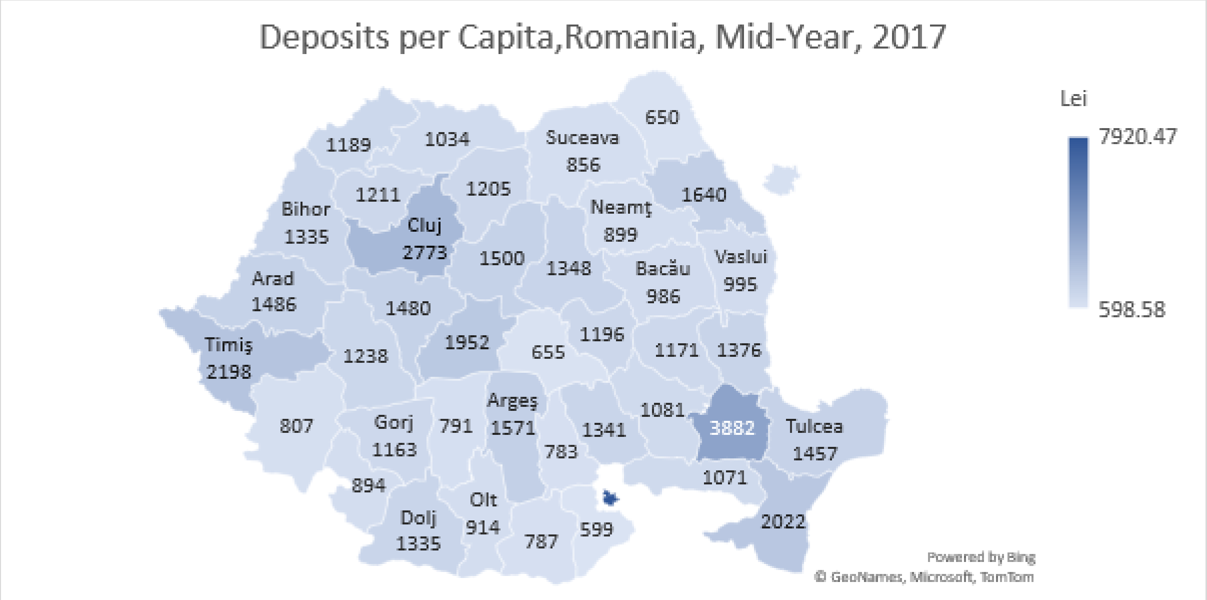


Fig. 7: Deposits per Capita by County, Romania, Mid-Year 2017 (Data Sources: National Bank of Romania, 2023; National Institute of Statistics - Romania, 2022)

According to the Bank Deposit Guarantee Fund (FGDB) in Romania, in 2017, there were 10,322,388 individual depositors. In the same year, a single depositor had deposited to 1.4 of the Romania FGDB member banks, on average (Bank Deposit Gurantee Fund, 2017). This, in effect, means that the actual number of individuals who held bank accounts could be as low as 7,142,857 individual dispositors. Of the population over the age of 14 on December 31, 2017 – 16,612,165 – the percentage of adults with bank accounts was a mere 43%. This contrasts with the Findex, which, in 2017, illustrates a different 58% (Bank Deposit Gurantee Fund, 2017). In 2019, the total number of bank branches had declined to 3,844 total branches – from 6,338 in 2008. Figure 5 demonstrates the decrease of bank branches, and the relative increase in ATMs in Romania.

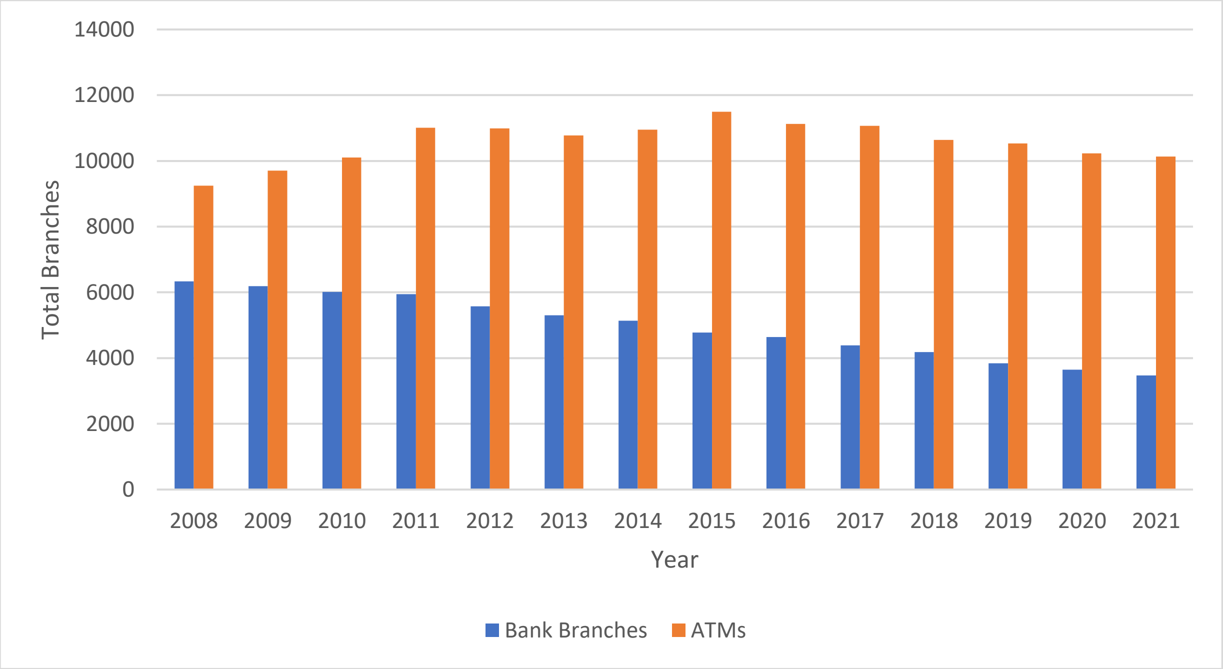


Fig. 8: Commercial Bank and ATM Branches, Romania, 2008-2021 (Data Source: IMF Access to Financial Data, 2023)

The GDP in Romania continues to increase, as with the level of deposits According to Amari, Anis, et al. (2021), evidence from the case of Tunisia points to an issue of exclusion resulting from distance from bank branches. However, contra to the issues discussed, in 2017 only 12.2% of respondents in Romania stated that the reason for financial exclusion was due to a branch being too far away (Demirgüç-Kunt, 2018). Financial education may play a role in the exclusion of individuals from financial products – as described by Drugă (2021), there was restraint and hesitancy for individuals to use financial products, as respondents felt that they lacked the in-depth knowledge to made accurate decisions (Drugă, 2021). Though proximity itself may not play a large role, the subsequent access to financial education could play a role. Moreover, as per Figure 8, there are fewer bank branches in each subsequent year since 2008, likely being replaced with ATMs.

There has been ample research to suggest that the current trends in financial inclusion in Romania remain stagnant, while in other parts of Europe these rates continue to increase. Moreover, there is research that indicates that there is a trend between increased income and urban living. Income tends to be an indicator of financial inclusivity, as does urban migration. These factors generally align with the data found in other places; however, Romania has had a somewhat stagnated urbanization rate. Research and discussion into the relationship between net migration and financial inclusion appears to be warranted based on these factors.

Remittances

Remittances received continue to have a large impact on the Romanian economy, rising from 0.93% of the total GDP of Romania in 2007 upon accession to the EU, up to 3.22% in 2021 (Kersan-Skabic & Tijanic, 2022). In absolute dollars, in 2006 total received remittances were $1.16 billion USD, which grew to $9.16 billion USD in 2021. Notably, between 2009 and 2012, remittances received as part of the GDP was less than that of the European Union. In contrast, the EU average for received remittances in 2021 was 0.78. Moreover, the level of remittances paid from the EU and Romania are inverse to that of remittances received. Romania's outbound remittance level was only 0.22% of the GDP of the country, whereas, the European Union had an outward remittance level of 0.71% of the GDP.

Compared to neighboring countries, the level of remittances to Romania is relatively low. In comparison to the 3.8B Euro that was remitted back to Romania from other EU countries – accounting for approximately 2% of the total GDP in 2017 (OECD, 2019). For example, remittances to Moldova represent up to 20% of the GDP, 14% of the Ukrainian GDP, 9% in Serbia, 3.5% in Bulgaria, and 3% in Hungary. There is evidence that suggests that this lower level of remittance from Romanians back home is due to the level of pay – in countries with higher levels of pay, there tends to be a higher level of remittance; whereas, from many European countries, levels of remittances are lower due to lower earned wages of the diaspora population (OECD, 2019).

Presumably, the lower remittances in the years 2008-2012 was due to the global financial crisis of 2008 (Roig & Recano, 2012). Prior to 2007, Morocco represented the highest number of foreign-born persons in Spain; however, in 2007, upon Romania's accession to the EU, Morocco moved to second behind Romania. In 2013, the remittances received in Romania rebounded quickly, and bounced to pre-crisis levels – up to 3.24% of the total Romanian GDP in 2019. Even during the COVID-19 Pandemic, in 2020 and 2021, remittances remained an important part of the Romanian economy. Figure 9 demonstrates the difference in remittances received as part of the GDP between 2005 and 2021 in Romania and the European Union. After the rebound of the financial crisis of 2008-2012, remittances to Romania jumped significantly, and remained high throughout the COVID-19 pandemic.

Roman (2013) provided insight as to determinants of remittance from Spain back to countries in Central and Eastern European Countries, with Romania in consideration. The level of education was a determinant of the level of remittance back to home countries – the higher the education, the greater the remittance paid. This could possibly be due to the income earned in the country of immigration. In contrast, the greater investment in the host country of immigrants was a predictor of lower remittances. In effect, if migrants had a greater number of investments in the new place, less would be sent back to the home country (Roman, 2013). Demographic factors, such as age, gender, or education are not determinants of remittance; however, education is a predictor of the amount of remittance.

Home ownership in the migrant's home country is a strong predictor of remittance behavior, as it was found that the money is remitted frequently to improve or build a new dwelling (Roman, 2013). This factor both influences the probability of remittance, and the level of remittance (Roman, 2013). Though Romanians are more prone to remit to their origin country, it does not represent a higher probability of remittance if one is Romanian. Finally, it was found that migrants who have relatives in their origin countries are more likely to remit back to their home country (Roman, 2013).

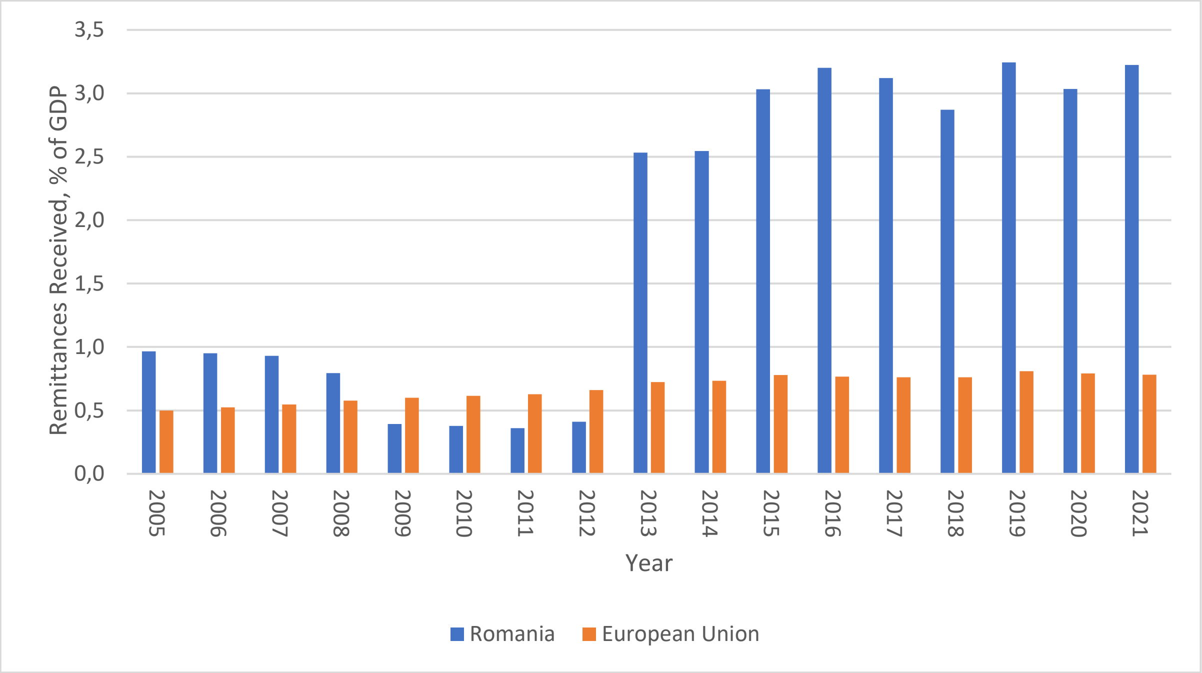


Fig. 9: Remittances Received, % of GDP, Romania and EU, 2005-2021 (Data Source, Eurostat, 2022)

Remittances received in Romania have become heightened since the accession to the European Union, and despite a drastic drop between 2009 and 2012 relative to the European Union, as a percent of the GDP derived from remittances received, the overall level of remittances has increased 400% since pre-financial crisis levels (Eurostat, 2022). Key reasons for these remittances appear to be family and ties to Romania (Roman, 2013). Goga (2020) suggests that as families grow away from their origin countries, the probability of sending remittances back home become lower. Education, age, and gender are not determinants of remittance; rather, they are indicators how levels of remittance. Determinants of remittance tend to be the types of relationships migrants have to their origin countries. Indeed, migrants with family members and permanent dwellings in Romania will continually send money back (Roman, 2013).

Methodology

Financial Inclusion Data

The data used in this research is taken from the World Bank Findex surveys from 2011, 2014, and 2017. The Findex is a triennial cross-sectional questionnaire that polls 1,000 samples from over 140 countries globally. The sampling is stratified by population size, geography, or both (World Bank Group, 2015). Weighting ensures that the data does not over-represent geographic regions, socio-economic groups, age, or individuals in various household sizes. Gallop Inc. has administered the Findex. The polling has been sponsored by the Development Research Group - Finance and Private Sector Development Unit of the World Bank, and the Bill and Melinda Gates Foundation provided financial support. There appears to be no conflict of interest in the funding or execution of the questionnaire. Questionnaires were administered in two main forms – face-to-face in 2011 and Computer Assisted Personal Interviews in 2014 and 2017. In all years, interviews were administered in both Romanian and Hungarian languages. All questionnaires were conducted during mid-year. The 2011 Findex questionnaire was administered from April 14, 2011, to May 12, 2011 (Demirguc-Kunt & Klapper, 2012). The 2014 Findex questionnaire was conducted from July 1, 2014, to August 12, 2014 (Demirguc-Kunt A. , Klapper, Singer, & Oudheusden, 2014). Finally, the 2017 Findex questionnaire was administered in Romania from April 12, 2017, to June 15, 2017 (Demirgüç-Kunt, 2018).

The specific Findex vectors that will be utilized are the ages - separated into age groups associated with the groups determined by the NIS, Financial Account Ownership, Income Quantile, and Level of Education. These data will act as variables to correlate against corresponding migration and urbanization data from the National Institute for Statistics – Romania. The data samples from the Findex are microdata – individual responses from the country.

Financial Inclusion Data Limitations

The most prominent limitation of the Findex is the frequency at which it is conducted. Trends are harder to identify when the number of data points are limited to triennial reporting. Moreover, the Findex is a cross-sectional survey - it does not track the same 1,000 participants each of the survey years. The weights are designed to provide a more vital comparison level. A broader range of factors can be included and adjusted for each survey depending on the country-level demographic and socio-demographic trends.

Migration Data

The National Institute of Statistics – Romania (NIS) draws country-specific data concerning migration and urbanization. The migration data is categorized into two main fields: temporary and permanent immigration and emigration. Temporary migration is considered when an individual is gone for at least 12 months – having left the country, but they have not de-registered from their home in Romania. In contrast, residence changes are associated with the permanent migration – those who may have registered elsewhere as residents and may let the government in Romania know they are not planning to return. These data – temporary and permanent migration, combined, provide total migration for a given year. This data tracks regionalities, development regions, and country-level migration; thus, this same data will be used to determine the total migration rates throughout the years.

Migration rates are tracked each year – both fields of migration differ in the mode in which they are tracked or estimated. Permanent changes are tracked by those individuals who change their legal residence to one abroad. In contrast, those listed as temporary are estimates based on correlating data sources. The NIS pulls data from the statistical offices of Italy and Spain, "mirror statistics" on international migration, and administrative data (National Institute for Statistics - Romania, 2022; National Institute for Statistics - Romania, 2022).

Migration Data Limitations

Though there are many benefits to using national data, it is not without its issues. The age categories and sex data differ between the two fields of migration data. This means that the study will not be able to include a gender-based discussion in the context of net migration rates and financial inclusion; however, permanent migration will be able to be discussed within the context of financial inclusion. Additionally, due to further constraints presented by temporary migration data tracking, specific ages are unavailable; therefore, only age groups can be used to determine relational aspects between FI and Migration rates. These age groups will be used to identify the most related groups between account ownership and migration patterns.

Data Analysis Methodology

In order to determine the relationship between migration and financial inclusion, correlation testing using Pearson's r will be based on data intervals. Spearman's coefficient was considered; however, the scales are not ordinal. Due to the limited number of survey years, it is challenging to distinguish between a statistical anomaly and a normal data point (Mukaka, 2012). Correlative tests will be administered to several groups of data to help identify a relationship between financial account ownership and migration & education levels.

Age-Group Specific Net Migration Rates

Due to limitations associated with data availability – especially in terms of the specificity related to the temporary migration rates- the National Institute for Statistics and Eurostat uses 5-year age groups. Moreover, the Findex data is only available every three years; for this reason, the migration data will be assessed based on a five-year average across each of the age groups. The population data will be used similarly, with corresponding age groups. To illustrate, the following data preparation will be completed for each age group in Romania.

Equation 1 Net Migration Rate

$$nm_{(x,t)} = \frac{(i_{(x,t-2)+}(i_{(x,t-1)+\cdots}\big(i_{(x,t+2)}\big) - \ (e_{(x,t-2)} + e_{(x,t-1)} + \cdots e_{(x,t+2)})}{p_{(x,t-2)} + p_{(x,t-1)} + \cdots p_{(x,t+2)}}$$

Where:
nm is Age (group) Specific Net Migration
x represents the age group
t represents the year calculated
i is the age-specific immigration
e is the age-specific emigration.

In the case of Romania, in the year 2011, for the age group 20-24, the syntax would be as follows:

Equation 1 Net Migration Rate, Age Group 20-24, Year 2011

$$nm_{(20-24,2011)} = \frac{(i_{(20-24,2009)+}i_{(20-24,2010)+} \dots i_{(20-24,2013)}) - (e_{(20-24,2009)} + e_{(20-24,2010)} + \cdots e_{(20-24,2013)})}{p_{(20-24,2009)} + p_{(20-24,2010)} + \cdots p_{(20-24,2013)}} \times 1000$$

$$nm_{(20-24,2011)} = \frac{834 + 615 + 2388 + 3592 + 3755 - 780 + 656 + 2021 + 2152 + 2245)}{1397944 + 1386794 + 1371513 + 1350389 + 1273671} \times 1000$$

$$nm_{(20-24,2011)} = \frac{2236.8 - 1570.8}{1,356,062.2} \times 1000$$

$$nm_{(20-24,2011)} = 0.49$$

Thus, the net migration for individuals between the ages of 20 and 24 in the year 2011, utilizing a 5-year average net migration calculation, indicates that there is nearly one person immigrating to Romania for every two-thousand people in that population category over the same period. Due to data limitations, these figures are those of permanent residential changes – individuals legally registered elsewhere as residents. This calculation will be used for each age group from 15 and above. The overall value in this is derived from smoothing the migration trend over two years preceding and two years after the Findex years.

The data presented by the NIS is that of years reached in the data year; thus, the individual's age is taken in the year. For example, as per the methodology presented by Caselli & Vallin (2006), a person who reached 24 years and 11 months by mid-year (July 1) would be considered 24 years (E Type 1). This method is usually used for longitudinal analyses; thus, it aligns with the purpose of a population-wide study over a long-term period (Caselli & Vallin, 2006).

Financial Inclusion Rates

Each survey year provides insight into global financial inclusion rates through microdata and macrodata. Macrodata is such that it provides a country-level rate amongst the variables – it is not dynamic and is limited in the scope of the possible uses; however, it is an adequate method of quickly observing the elemental trends. For this research, Findex Microdata will be the primary database. The microdata is the individual responses from each of the country-level sample units. In each of the years, the total number of respondents is weighted to be 1,000 total; thus, the survey represents 1,000 respondents even though, for instance, only 998 sample units successfully completed the survey within Romania in 2011. The rate of inclusion and exclusion based on account ownership will be the variables analyzed – including account ownership rates with respect to income quantile and education. These rates will be used to cross-examine, by way of correlative testing and regression analysis, the relationship, if any, between migration and the Findex rates.

The calculation of the inclusion rate will be as follows:

Equation 3 Financial Inclusion Rate

$$FR_t^x = \frac{\sum_x^t w_i}{\sum_x^t w}$$

Where:

FR is the Financial Inclusion Rate

x is the age group

t is the year observed

wi is the weight of the respondents with accounts

w is the weight of all respondents in the corresponding cohort

As an example, using the Romanian (ROU) data from the Findex to determine the financial inclusion rate of individuals in 2011 between the ages of 20-24, the following formula would be used:

Equation 4 Financial Inclusion Rate, Age Group 20-24, Year 2011

$$FR_{2011}^{20-24} = \frac{53.83}{95.29}$$

$$FR_{2011}^{20-24} = 0.56$$

Therefore, based on the example of 20-24 during the 2011 survey year, the weighted total Financial Inclusion rate is 0.56 (56%). By tracking this from survey year to survey year, the rate changes can be postulated to represent the changing financial inclusion rates of the population in the age group listed in the equation. Education and income quantiles will be calculated using the same method.

Correlation Testing

This study aims to identify if there is a relationship between two variables on a non-ordinal scale. For this reason, Pearson's r coefficient will be utilized. The data that will be examined will be Age-Specific Net

Migration Rates from Romania against various Age-Specific Financial Inclusion Rates. Pearson's r coefficient will be calculated as such:

Equation 5 Pearson R Correlation Coefficient

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

As there is no distinction between dependent and independent variables in the case of Pearson's coefficient, Age-Specific Net Migration Rates will serve as the x, and the Age-Specific financial inclusion Rates will serve as the y variables. These variables will remain the same for regression analyses. The same method will be utilized in order to identify a relationship between net migration and age-specific quantile-specific financial inclusion rates.

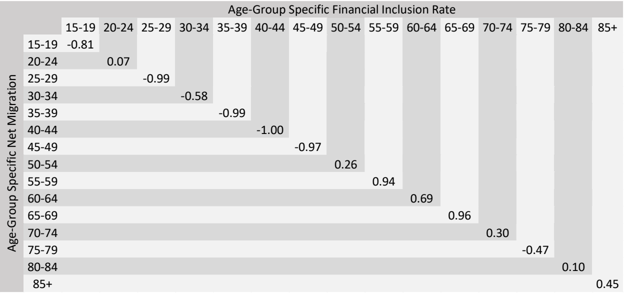
Results and Discussion

Initial findings were quite interesting and aligned well with the expected results based on previous literature regarding the changes in migration due to brain drain. Individuals of University age – 20-24 had increased age-specific net migration, while the age-specific migration of those 25-29, 35-39, 40-44, and 45-49 all consistently saw net negatives in 2014 and more drastically in 2017, based on the 5-year net migration averages. What is notable about this data is the strength of the correlation between age-specific net migration rates and age-specific financial inclusion rates.

Correlative Tests

Correlative testing was utilized to determine whether there may be a relationship between the sets of tested variables – migration and financial inclusion rates. In these tests, there were several considerably significant findings. The Pearson r method was utilized, as it is non-ordinal data. The null hypothesis was that the two variables were independent of each other and there would be no correlation. The correlations were negatively significant in the age groups 25-29, 35-39, 40-44, and 45-49.

Figure 10 highlights the Pearson R coefficients of several age groups with strong correlative associations, including groups 25-29, 35-39, 40-44, 45-49, 55-59, and 65-69. The latter two are positive correlations and may be explained as an inverse relationship to those with strong negative correlations. These strong negative correlations indicate an association between the Age-Group Specific Net Migration Rate and the Age-Group-Specific Financial inclusion Rate, where there is increased outbound migration, as Goga (2020) discussed. Many are educated as observed in the testing between. Moreover, an increased net migration inflow for the ages 55-59 and 65-69 illustrates a possible relationship between the two variables. A possible reason for this is that individuals in this age group return from abroad at pensioner age; thus, it would explain the increase in both variables (Snel, Faber, & Engbersen, 2015). In line with the research completed regarding the ages of individuals leaving the country and why, Goga's (2017) explanation touches on those who have finished university, which can explain why those are 20-24 such a low correlation between inclusion and migration. Though there appears to be some change to account ownership, it is not significant enough to be considered associated.



	Age-Group Specific Financial Inclusion Rate														
Age-Group Specific Net Migration	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74	75-79	80-84	85+
15-19	-0.81														
20-24		0.07													
25-29			-0.99												
30-34				-0.58											
35-39					-0.99										
40-44						-1.00									
45-49							-0.97								
50-54								0.26							
55-59									0.94						
60-64										0.69					
65-69											0.96				
70-74												0.30			
75-79													-0.47		
80-84														0.10	
85+															0.45

Fig. 10: Correlation by Age Group, Net Migration Rates, and Financial Inclusion Rates, 2011-2017

An interesting finding that is somewhat addressed by the flow of labor from developing countries to many developed countries is the strong negative correlation between net migration rates and the age-specific rates of financial account ownership for the age groups 40-44 and 45-49. For the age group 30-34, the correlation between net migration and financial inclusion rates for those who have secondary school only, and those with tertiary or more education, is -0.78 and -0.92, respectively – both of significant importance.

Table 1: Pearson's r Coefficients, Net Migration and Financial Inclusion by Education Level Attainment, Romania, 2011-2017 (Data Sources: Own Calculations, based on data from NIS, 2022, World Bank Findex, 2022)

Pearson r Coefficient, Age-Specific Net Migration and Age-Specific Financial Inclusion by Income Quantile, Romania, 2011-2017				
Age Group	**Age-Specific FI**	**Primary**	**Secondary**	**Tertiary**
15-19	-0.81	-0.12	-0.74	-0.95
20-24	0.07	0.80	-0.37	-0.11
25-29	-0.99	0.89	-0.99	-0.99
30-34	-0.58	0.73	-0.24	0.02
35-39	-0.99	-0.23	-1.00	0.84

40-44	-1.00	0.99	-0.98	0.00
45-49	-0.97	-0.89	-0.67	0.57
50-54	0.26	0.16	0.21	-0.77
55-59	0.94	0.58	-0.24	0.98
60-64	0.69	-1.00	0.84	0.90
65-69	0.96	0.93	0.96	0.98
70-74	0.30	-0.08	0.93	0.92
75-79	-0.47	-1.00	-0.60	-0.62
80-84	0.10	-0.52	-0.98	-0.38
85+	0.45	-0.93	0.55	0.99

Table 1 provides the outputs for Pearson’s r correlative coefficients using the variables of age-specific net migration rates and age-specific financial inclusion rates based on the highest level of educational attainment. What is interesting about these figures is how closely related the primary and secondary education attainment data are to the migration and financial inclusion rates of the entire age group. There are several age groups that offset one group with another by relationship with migration. For example, the age groups 25-29, 35-39, 40-44, and 45-49 show considerably coefficients, and they are all represented quite well by way of secondary school education. There appears to be a very strong relationship between these variables.

Results from correlative testing between age-specific net migration and financial inclusion by income quantiles provide insight into possible links between socioeconomic groups and the way in which migration may affect their levels of financial inclusion. Key age groups are those 25-29, 35-39, 40-44, and 45-49. In all these circumstances, the highest negative correlations appear in the 2nd, 3rd, and 4th income quantiles. Notable findings are those in the categories 25-29, 30-34, and 45-49, which emphasize the inverse relationship between income-quantile distribution, financial inclusion, and migration. In plain terms, net migration has the strongest relationships with the middle-income quantiles.

Table 2: Pearson's r Coefficient, Age-Specific Net Migration and Age-Specific Financial Inclusion Rate by Income Quantile, Romania, 2011-2017 (Data Sources: NIS, 2022, World Bank Findex, 2022)

Pearson r Coefficient, Age-Specific Net Migration and Financial Inclusion by Income Quantile, Romania, 2011-2017						
	Age-Specific FI	Q1	Q2	Q3	Q4	Q5
15-19	-0.81	-0.43	-0.24	-0.99	-0.67	-0.99
20-24	0.07	0.03	1.00	-0.81	-0.96	-0.39
25-29	-0.99	0.06	0.72	-0.87	-0.85	0.21
30-34	-0.58	0.19	-0.84	-0.27	-0.60	-0.71
35-39	-0.99	0.21	-0.30	-0.70	-0.87	-0.86
40-44	-1.00	-1.00	-0.87	-0.68	-0.88	0.74
45-49	-0.97	0.56	-0.86	-0.95	-0.13	-0.83
50-54	0.26	0.98	-0.17	-1.00	0.65	0.20
55-59	0.94	-0.55	0.33	0.86	0.64	0.35
60-64	0.69	-0.76	0.98	0.64	0.91	0.65
65-69	0.96	-0.54	0.90	0.91	0.32	0.99
70-74	0.30	-0.66	-0.05	0.60	0.98	0.73
75-79	-0.47	0.32	-0.99	-1.00	-0.06	-0.02
80-84	0.10	-0.99	-0.39	-0.58	-0.48	-0.88
85+	0.45	-0.91	-0.94	-0.94	-0.74	-0.81

Regression Analyses

In response to correlative testing and the indications that migration is the cause of changes in financial inclusion by way of brain drain and exit of employable persons, linear regression analyses have been conducted. In the analysis, p-Values, Significances, and multiple r regression have been observed with similar results to correlative tests. Only two variables have been tested by way of linear regression, as the number of variable points is limited.

Results: Regression Analyses: Migration (x) and Financial Inclusion (y)

When observing the linear regression analysis outputs, certain age groups had greater statistical significance than others. It was discovered that when observing key age groups associated with the correlative tests conducted, the Anova p-values were statistically significant for those same age groups with strong negative correlations. Age groups 25-29, 35-39, 40-44, and 45-49 all show a significance of less than 0.01 (1%); thus, their probability of occurring under normal circumstances is below 1% - a highly significant finding.

Table 3: Regression Analysis Outputs by age groups, 2011-2017, Net Migration (x) and Financial Inclusion (y) (Data Source: Own Calculations)

Linear Regression Analysis, Age-Specific Net Migration (x), and Age-Specific Financial Inclusion Rates (y)			
Age Group	**Pearson R**	**Multiple R**	**p-Value**
15-19	*-0.81*	*0.81*	*0.563*
20-24	*0.07*	*0.07*	*0.113*
25-29	*-0.99*	*0.99*	*0.008**

30-34	*-0.58*	*0.58*	*0.157*
35-39	*-0.99*	*0.99*	*0.008**
40-44	*-1.0*	*1.0*	*0.0004**
45-49	*-0.97*	*0.97*	*0.030***
50-54	*0.26*	*0.26*	*0.314*
55-59	*0.94*	*0.94*	*0.129*
60-64	*0.69*	*0.69*	*0.253*
65-69	*0.96*	*0.96*	*0.257*
70-74	*0.30*	*0.30*	*0.179*
75-79	*-0.47*	*0.47*	*0.022*
80-84	*0.10*	*0.10*	*0.242*
85+	*0.45*	*0.45*	*0.235*

* Significance level of <0.01 ** significance level of <0.05

The outlier regarding p-values happens to be the age group of 75-79 – an age group with an insignificant correlation between migration and financial inclusion. However, the association is considered statistically significant because it would be outside the null hypothesis that there would be no relationship between the two variables. The age groups of 25-29, 35-39, and 40-44 had a significance level of <0.01 – which provides evidence for and corroborates the hypothesis that migration impacts financial inclusion. The age group, 45-49, shows a significance level of <0.05 (0.030) with a Multiple R of -0.97. Migration and the subsequent change in financial inclusion rates are observed to have a strong relationship.

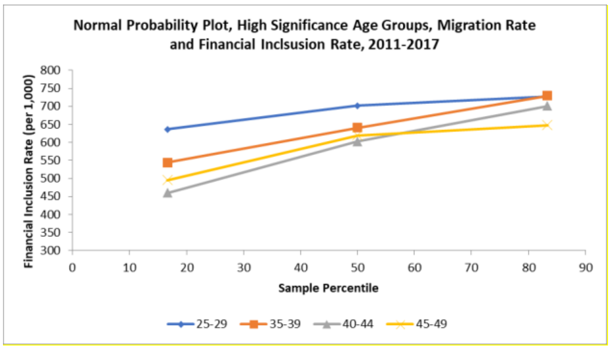


Fig. 11: Normal Probability Plot, High Significance Age Groups, Migration Rate, and Financial Inclusion Rates, 2011-2017 (Data Source: Own Calculation)

Figure 11 illustrates the closeness of data for age groups based on Net Migration Rates (per 1,000) (x variable) and the Financial Inclusion Rate (per 1,000) (y variables). In years with positive net migration, the rate per 1,000 of Romanians have financial accounts, while in years with lower net migration, there are, per 1,000, fewer who own accounts at formal financial institutions.

Discussion

Some of the most interesting findings occurred in several age categories - 25-29, 35-39, 40-44, and 45-49- these age groups were found to have significant inverse relationships between net migration and financial inclusion. There were some other significant observations to consider – those who were 60-64 and 65-69 had positive correlations between migration and financial inclusion, meaning that this group had increased positive net migration and financial inclusion rates. This may be due to individuals returning at retirement age and utilizing financial accounts. As Roman (2013) discussed, individuals with ties back home are more likely to remit money and potentially return home. What is interesting about the over-55 population was the strong positive correlation between inward migration and greater financial inclusion – notably, the 55-74 age groups had an r>0.89.

The evidence presented in this research points to a significant relationship between net migration rates and financial inclusion rates. This has been postulated to be because those in the select age groups seek work and higher pay. The otherwise unbanked in the country remain, causing a spike in the exclusion rates within their respective age categories. This may be corroborated in the level of inverse correlation discovered for individuals in the 2nd, 3rd, and 4th income quantiles and those with secondary school education. Further research is necessary to determine the true impact of county-specific exclusion rates and internal migration rates' impact on financial inclusion. Understanding county-level financial literacy and specific financial inclusion rates may provide more insight into the true impact of financial literacy.

What can be gathered from this data is that individuals at the beginning and middle of their careers are leaving Romania behind, resulting in lower financial inclusion rates within the formal banking system. This may have detrimental long-term effects so long as those who migrate remain outside Romania into their pensioning years. Fewer accounts may ultimately result in more individuals who will be paid in cash, contribute less to social welfare systems, and be less likely to receive electronic transfers from the government. Moreover, the results can be even more impactful to human capital investments, with fewer taxes paid and fewer skilled individuals available per individual.

It is not all bad, however, as there is evidence to suggest, based on this research, that migration also affects the remittance rates in Romania. The level of remittances as a proportion of GDP has continued to rise despite the stagnation of financial inclusion rates.

This has been especially evident in the main region of Bucharest; however, it has also been found in other smaller counties. The year-over-year increase has contributed to the economy – albeit at a lower rate than neighboring countries. Remittances are predicted to continue to play a role in the development of the Romanian economy in the future; however, as Roman (2013) points out, there is a chance that individuals may remit less when there are fewer ties home. With the quickly aging population of Romania on its current trajectory, there is a question of how long these remittances will last.

When considering the impact of depopulation, a perpetual outward migration will have a double-edged negative effect on the country – lower investments and fewer individuals contributing into the economy. Greater long-term diaspora will also result in a perpetual, and potentially accelerated depopulation from a combination of lower birth rates within the country, a rapidly aging population, and a greater number of job seekers leaving for better opportunities elsewhere with family. Romania continues to develop at a rapid rate, and the economy certain does continue to grow. The future of financial utilization in Romania remains to be seen – the lower number of formal bank branches, mixed with an increased number of ATMs indicates that there may be a requirement for more third-party financial education to the under-banked.

Conclusion

Migration and depopulation have been significant issues in Romania since the fall of Communism and have been especially problematic since Romania acceded to the European Union in 2007. Since 1991, it Is estimated that over 3.5 million Romanians have left the country, and the population has dropped significantly due to a mix of outward migration, low fertility rates, and low immigration rates. The first Findex publication in 2011 illustrated Romania as a country with low financial inclusion rates – some of the lowest in Europe and Central Asia. In the years since 2011, rates increased to 63% in 2014, and dropped again in 2017 to 58%.

Romania's poorest population is the most underbanked in many situations but is not the cause of declining rates of inclusion; rather, these poorest individuals tend to be more well banked year-over-year. Based on data gathered from the research conducted by Goga (2017; 2022), the hypothesis was presented that changing financial inclusion rates were driven by outward migration. Individuals leaving the country are doing so in order to find a better life by way of finding gainable employment or greater pay. After accession to the EU in 2007, migration has become more rapid. The slowdown between 2008 and 2012 during the global financial crisis was quickly overshadowed by rapid net negative migration.

It was discovered that in the age groups 25-29, 35-39, 40-44, and 45-49, there were quite strong correlations: -0.987, -0.995, -1.0, and -0.972, respectively. Moreover, the significance level was <0.01 for all these age categories using linear regression. This discovery corroborates the assertion that outward migration impacts Romania’s financial institution utilization. What was interesting about migration and financial inclusion were the income quantiles and education levels of those who saw much of the change in relation to the migration rates. In particular, the aforementioned age groups were of great interest, but it was predominantly those in the 3rd and 4th income quantiles who were most inversely correlated between FI and net migration.

It is not all bad, however, as some indicators of increased migration and account ownership were linked in a few age groups, predominantly in those preparing for retirement. Age groups of 55-59, 60-64, and 65-69 saw correlations of 0.936, 0.694, and 0.959, respectively. This indicates increased net migration toward Romania, with increased financial inclusion rates in these age groups. However, the significance level is not as high as those in the younger age groups. These outputs allow this research to postulate a strong relationship between migration and financial inclusion for select age groups. Moreover, remittances continue to play a strong role in the development of Romania’s economy and will likely continue to do so in the future as the Romanian diaspora continues to grow.

Financial inclusion, much like migration, is a challenging subject to discuss in general terms. Just as there are many reasons for people to leave a country, there are many reasons for individuals to remain unbanked. In Romania, those leaving the country appear to be leaving behind those who have traditionally remained excluded from the system, voluntarily or involuntarily. Further research must be conducted to determine the specific regions of importance in terms of financial inclusion rates and investigate how internal migration and mortality rates have affected financial inclusion – if at all. Slowing migration-related depopulation may have a positive impact on the financial inclusion rate, thereby increasing the overall standard of living and speed of development in the Romanian economy.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

References

Alexe, I., Cazacu, A., Ulrich, L., Stanciugelu, Ș., Mihăilă, V., & Bojincă, M. (2011). Migrația creierelor pe ruta România-Occident. *Editura Fundația Soros România.*

Allen, F. D.-K., Klapper, L., & Martinez Peria, M. S. (2016). The foundations of financial inclusion: Understanding ownership and use of formal accounts. *Journal of Financial Intermediation*, 1-30.

Altarawneh, Y., Al-Nimri, A., & Al-Nuaimi, M. (2020). The Determinants of Financial Inclusion in Latin America and Europe (Brazil and Romania Case). *International Journal of Innovation, Creativity and Change*, 12(2).

Amari, M., & Anis, J. (2021). Exploring the impact of socio-demographic characteristics on financial inclusion: empirical evidence from Tunisia. *International Journal of Social Economics*, 48(9).

Bank Deposit Gurantee Fund. (2017). *2017 Annual Report*. Bank Deposit Gurantee Fund.

Basix, V. M., & Ramola, B. G. (1996). Financial Services for tge Rural Poor and Women in India: Access and Sustainability. *Journal of International Development*, 8(2), 211-224.

Bleahu, A. (2004). Romanian migration to Spain. Motivation, networks and strategies. *New Patterns of Labour Migration in Central and Eastern Europe*, 21-35.

Borjas, G. J., & Bronars, S. G. (1996). Who Leaves? The Outmigration of the Foreign-Born . *The Review of Economic Statistics*, 78(1), 165-176.

Botezat, A., & Moraru, A. (2020). Brain Drain from Romania: What do we know so far about the Romanian medical diaspora? *Eastern Journal of European Studies*, 309-334.

Cabeza-Garcia, L., Brio, E. B., & Oscanoa-Victorio, M. L. (2019). Female financial inclusion and its impacts on inclusive economic development. *Women's Studies International Forum*.

Caselli, G., & Vallin, J. (2006). From Situating Events in Time to the Lexis Diagram and the Computing of Rates. In *Demography Analysis and Synthesis - A Treaties in Population* (pp. 55-68). Burlington MA: Elsevier.

Chakrabarty, K. (2011, 10 12). Financial Inclusion | A road India needs to travel - Speech. Mumbai, India.

Chindea, A., Majkowska-Tomkin, M., Mattila, H., & Pastor, I. (2008). *Migration in Romania: A Country Profile 2008*. Geneva: International Organization for Migration.

Danisman, G. O. (2020). Financial inclusion and bank stability: evidence from Europe. *The European Journal of Finance*, 1842-1855.

Demirgüç-Kunt, A. L. (2018). *The Global Findex Database 2017: Measuring Financial Inclusion and the Fintech Revolution*. Washington DC: World Bank.

Demirguc-Kunt, A., & Klapper, L. (2013). Measuring Financial Inclusion: Explaining Variation in Use of Financial Services across and within Countries. *Brookings Papers on Economic Activity*, 279-340.

Demirguc-Kunt, A., & Klapper, L. F. (2012). *Measuring Financial Inclusion: The Global Findex Database*. Washington DC: World Bank.

Demirguc-Kunt, A., Klapper, L., Singer, D., & Oudheusden, P. V. (2014). *The Global Findex Database 2014: Measuring Financial Inclusion around the World*. Washingtonn DC: World Bank.

Demirguc-Kunt, A., Klapper, L., Singer, D., & Oudheusden, P. V. (2015). *The Global Findex Database 2014- Measuring Financial Inclusion around the World*. Washington DC: World Bank Group.

Drugă, R.-I. (2021). Financial Education, a Challenge for the South and Eastern European Countries - Case Study Romania. *9th ASECU Youth International Conference and Summer School & 10th Jubilee Summer School of the Faculty of Economics - Skopje*, 87-96.

Enache, N., & Gonzalez Rabanal, M. (2018). Migration of Labour Force in the European Countries. *Supplement of Valahia University Law Study* (pp. 251-265). Târgovişte: Facultatea de Drept şi Ştiinţe Administrative.

Eurostat. (2022). *Personal remittances statistics*. Brussels: European Commission.

Gavriloaia, G.-C. (2020). The impact of the brain drain process on Romania - possible solutions in order to increase resilience. *CES Working Papers*.

Gherhes, V., Dragomir, G.-M., & Cernicova-Buca, M. (2020). Migration Intentions of Romanian Engineering Students. *Sustainability*, 4846.

Girard, T. (2021). *Explaining the Origins and Evolution of the Global Financial Inclusion Agenda*. London Ontario: Scholarship@Western.

Goga, C. I. (2020). Is Romania in a social and economic crisis caused by emigration? The new policy of the Romanian state on migration. Sociology and Social Work Review, 31-37.

Goga, C. I., & Ilie, V. (2017). From "brain drain" to "brain gain". Where does Romania stand? *Revista de Științe Politice. Revue des Sciences Politiques*(54), 90-103.

Harris, J. R., & Todaro, M. P. (1970). Migration, Unemployment and Development: A Two-Sector Analysis. *The American Economic Review*, 60(1), 126-142.

Huang, R., Kale, S., Paramati, S. R., & Taghizadeh-Hesary, F. (2021). The nexus between financial inclusion and economic development: Comparison of old and new EU member countries. *Economic Analysis and Policy*, 69, 1-15.

Jafar, K. (2020). Impact of migration on financial inclusion and local financial systems in Kerala 1. In *India Migration Report 2020*. Routledge India.

Kersan-Skabic, I., & Tijanic, L. (2022). The impact of remittances on economic development in the Central and Eastern European Countries. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu*, 281-296.

Klapper, L., & Demirguc-Kunt, A. (2012). Measuring Financial Inclusion: The Global Findex Database. *World Bank Policy Research Paper*.

Kuhlenkasper, T., & Steinhardt, M. F. (2017). Who leaves and when? Selective outmigration of immigrants from Germany. *Economic Systems*, 41(4), 610-621.

Mohan, R. (1996). *State of the Indian Economy*.

Mukaka, M. (2012). Statistics Corner: A guide to appropriate use of Correlation coefficient in medical research. *Malawi Medical Journal*, 24(3), 69-71.

Nae, T.-R. (2013). Migration and its Effects on Economic and Demographic Development in Romania. *Mediterranean Journal of Social Sciences*, 35-43.

National Institute for Statistics - Romania. (2022). *Permanent emigrants by age group, macroregions, development regions and counties of departure*. Retrieved 05 19, 2022, from http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table

National Institute for Statistics - Romania. (2022). *Temporary emigrants by agr group, sex, urban/rural area*. Retrieved 05 19, 2022, from http://statistici.insse.ro:8077/tempo-online/#/pages/tables/insse-table

OECD. (2019). *Talent Abroad: A Review of Romanian Emigrants*. Paris: OECD Publishing.

OECD. (2022). *International Migration Outlook 2022*. Paris: OECD Publishing.

Otovescu, C., & Otovescu, A. (2019). The Depopulation of Romania – Is It an Irreversible Process? *Review of Research and Social Intervention*(65), 370-388.

Ozili, P. K. (2020, 01 25). Financial inclusion research around the world: A review. *Forum for Social Economics*, 50(4), 457-479.

Pham, M. T., Nguyan, V. H., & Ngo, M. N. (2022). The Impact of Financial Inclusion on Income Inequality: Case Study in Europe. *Economic Insight - Trends and Challenges*, 33-45.

Popescu, A. (2022). Income Inequality in the Countries of the European Union. *Management, Economic Engineering in Agriculture and Rural Development*, 547-560.

Popescu, D., Georgina Picu, C., & Popescu, A.-C. (2018). Empirical Research Regarding the Migration of Highly Qualified Human Resources from Romania - Examples from the Medical Field. *European Journal of Sustainable Development*, 463-472.

Pumain, D. (2006). The Urbanization Process. In *Demography Analysis and Synthesis - Treatise in population* (pp. 319- 330). Burlington: Elsevier.

Roig, M., & Recano, J. (2012). The Impact of the Global Financial Crisis on Migration to and Remittance Flows from Spain. *Papers de Demografia*, 1-19.

Roman, M. (2013). Financial Effects of International Migration in Europe: Modelling the Decision to Remit. *Panoeconomicus*, 541-555.

Sandu, D. (2012). 13 Modernising Romanian Society Through Temporary Work Abroad. *A Continent Moving West?*, 271.

Sarma, M. (2008). *Index of Financial Inclusion*. New Delhi: Indian Council for Research on International Economic Relations.

Sarma, M., & Pais, J. (2011). Financial Inclusion and Development. *Journal of International Development*, 613-628.

Selod, H., & Shilpi, F. (2021). Rural-urban migration in developing countries: Lessons from the literature. *Regional Science and Urban Economics*, 91.

Snel, E., Faber, M., & Engbersen, G. (2015). To Stay or Return? Explaining Return Intentions Of Central and Eastern European Labour Migrants. *Central and Eastern European Migration Review*, 5-24.

Tarsem, L. (2018). Impact of financial inclusion on poverty alleviation through cooperative banks. *International Journal of Social Economics*, 807-827.

The World Bank Group. (2020). *Financial Inclusion in Romania: Issues and Opportunities*. Washington DC: The World Bank.

Todaro, M. P., & Smith, S. C. (2015). Urbanization and Rural-Urban Migration. In M. P. Todaro, & S. C. Smith, *Economic Development* 12e (pp. 330-374). Pearson.

United Nations, Department of Economic and Social Affairs, Population Division. (2022). *World Population Prospects: The 2022 Revision*. United Nations.

World Bank. (2011). *Migration and Remittances Factbook 2011*. Washington DC, United States: World Bank.

World Bank. (2020). *Financial Inclusion in Romania: Issues and Opportunities*. Washington DC: The World Bank Group.

World Bank. (2021). *Survey Methodology*. Washington DC: The World Bank Group. Retrieved from https://thedocs.worldbank.org/en/doc/f3ee545aac6879c27f8acb61abc4b6f8-0050062022/original/Findex-2021-Methodology.pdf

World Bank Group. (2015, 04 15). *Global Financial Inclusion (Global Findex) Database 2011 - Study Description*. Retrieved from The World bank Microdata Library: https://microdata.worldbank.org/index.php/catalog/1234

World Bank Group. (2021). *Financial Inclusion Overview*. Retrieved from The World Bank: https://www.worldbank.org/en/topic/financialinclusion/overview#1

World Bank Group. (2021). *Migration and Remittances Data*. Retrieved from World Bank Group: https://www.worldbank.org/en/topic/migrationremittancesdiasporaissues/brief/migration-remittances-data

World Bank Group. (2021). *Net migration - Greece*. Retrieved from World Bank Group - Data: https://data.worldbank.org/indicator/SM.POP.NETM?locations=GR

World Bank Group. (2021). *Net Migration - Romanina*. Retrieved from World Bank Group - Data: https://data.worldbank.org/indicator/SM.POP.NETM?locations=RO

World Bank Group. (2021). *Net migration - Serbia*. Retrieved from World Bank Group - Data: https://data.worldbank.org/indicator/SM.POP.NETM?locations=RS

World Bank Group. (2021). *The Drive for Financial Inclusion: Lessons of World Bank Group Experience*. World Bank Group, Independent Evaluation Group. Washington DC: World Bank Group.