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Soil pollution prevention and control measures in China

Claudio DELANG[1,*]

[1] Department of Geography, Hong Kong Baptist University, Kowloon Tong, Hong Kong
* *Corresponding author*:

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Abstract

Soil pollution is a major problem in China. This paper describes the policies that the government has undertaken to remedy the situation, by either preventing additional pollution, or reducing the existing pollution levels. First, China is honing the legal framework to protect arable lands, control sources of pollution, and assess, manage and clean up polluted sites. Second, the government has made steps to improve the identification and monitoring of pollution sources. Third, the government has promoted chemical and biological technologies to lower the level of soil pollution. In spite of these efforts, there are still considerable challenges. First, China has considerable economic, social, and environmental diversity, so uniform top-down designed policies are likely to face considerable problems in many areas. Second, the local institutions trusted with the soil pollution cleanup have little understanding about clean soil standards, the right technology for soil inspection and treatment, and the management strategies for vast areas of land. In addition, the costs of cleaning up the land are staggering, with estimates ranging from CNY 6 to 11 trillion, with little potential for cost recovery from soil rehabilitation.

Keywords: *soil pollution, pollution prevention, China*

Rezumat. Măsuri de prevenire și control al poluării solului în China

Poluarea solului este o problemă majoră în China. Lucrarea de față descrie politicile implementate de guvern spre a remedia situația, fie prin prevenirea poluării adiționale, fie prin reducerea nivelului existent de poluare. În primul rând, China își pune la punct cadrul legal pentru protejarea terenurilor arabile, pentru controlul surselor de poluare și pentru evaluarea, managementul și reabilitarea siturilor poluate. În al doilea rand, guvernul a întreprins acțiuni pentru îmbunătățirea identificării și monitorizării surselor de poluare. În al treilea rând, guvernul a promovat tehnologii chimice și biologice cu scopul de a scădea nivelul de poluare a solului. În ciuda acestor eforturi, încă există provocări semnificative. China este caracterizată printr-o considerabilă diversitate economică, socială și environmentală, deci politicile uniforme de tip *top-down* pot întâmpina probleme serioase în multe areale. Mai mult, instituțiile locale responsabile cu reabilitarea siturilor afectate de acest tip de poluare nu dispun de cunoștințele necesare cu privire la standardele pentru soluri nepoluate, de tehnologia potrivită pentru inspecția și tratamentul solurilor, sau de strategiile de management al unor suprafețe extinse. In plus, costurile pentru reabilitarea terenurilor sunt foarte mari, estimările fiind între 6 și 11 trilioane CNY, iar potențialul de amortizare a cheltuielilor prin reabilitarea solului este redus.

Cuvinte-cheie: *poluarea solului, prevenirea poluării, China*

Introduction

In 2013, Beijing's lawyer Dong Zhengwei requested soil pollution data from the Ministry of Environmental Protection, including information on the causes and methods for dealing with the problem. The request was declined on the grounds that the data was a "state secret". Nevertheless, at the end of 2013, the government released limited information on soil pollution, partly because of the strong public reaction against that refusal. Despite the lack of details, the released data caused widespread concern (He, 2014a). In April 2014, the government issued a more comprehensive report about the country's soils (He, 2014b). The report shows that 16.1 per cent of the soil samples (19.4 per cent for agricultural soils) are contaminated with organic and chemical contaminants, as well as heavy metals and metalloids such as lead, cadmium, and arsenic (Zhao et al., 2014). Chinese officials say that an area the size of Taiwan is so polluted that farming should not be allowed there at all (Wong, 2014).

Removing the pollutants from the soil requires concerted efforts. The rehabilitation of polluted soil is a major challenge, especially if the pollutants are heavy metals. Polluted air is blown away and polluted water flows down rivers, so if the emissions stop, the pollutants in the air and water will dilute. On the other hand, pollutants in the soil will remain there for decades, if not treated. This means that efforts and expenses to alleviate the soil pollution problems may eventually far exceed those made to address air and water pollution (Delang, 2016a, 2016b). As Zhuang Guotai, the head of the Ministry of Environmental Protection's Department of Nature and Ecology Conservation, said, "In comparison with efforts to clean up air and water pollution, we've hardly got started with soil. But once the market is opened up, soil remediation will be on a far bigger scale than either air or water cleanup" (He, 2014a).

This paper describes the approach used by the government to tackle the problem of soil pollution. It first delves into the development of the legal framework, which has been lacking until relatively recently. This also involves the re-classification of soil use, to limit the impact of soil contamination. It then looks at the efforts expended identifying and monitoring the sources of pollution. Next, the paper discusses the technologies being developed and applied to reduce soil pollutants. Existing technologies are expensive, so China is also making an effort to develop cheaper technologies, given the extent of the problem (20 million ha of arable land are contaminated), and the likely costs involved (between CNY 6 and 11 trillion). Finally, it deals at the challenges that exist, given China's political organization and level of economic development, to address soil pollution.

Development of the legal framework

Although the authorities were a little slow to realize the magnitude of the soil pollution problem in China, there are now hopeful signs that the government is starting to deal with the problem (He, 2014c). Urgent action is needed, as the heavy metals and metalloids are already entering the food chain. The solutions start with more stringent laws, better technology to treat the soil, and additional funding (Zhao et al., 2014).

Laws about soil pollution

There is a lack of regulations governing soil pollution prevention and control in China, and without laws directly addressing these issues, cases can only be tried as a national tort or criminal offence, which does not ensure environmental remediation. Furthermore, the tort law is ineffective, and criminal laws addressing soil pollution are rarely invoked (Drenguis, 2014).

The government has made some efforts to introduce laws that directly address soil pollution. For example, in 1995, it approved a law (promulgated the following year) on the prevention and control of environmental pollution by solid waste, which also considered soil protection (Mu et al., 2014). However, this law is weakly enforced because the articles are ambiguous, the fines insufficient, and local governments have no incentive to enforce the laws (Drenguis, 2014).

Drenguis (2014) argues that while seemingly well-intentioned, the laws are more akin to policy statements than substantive legal requirements. For example, Article 55 of the Solid Waste Law does not define what "relevant provisions" or "specified periods of time" refer to when discussing the management of hazardous waste. By the same token, in Article 32 of the Environmental Protection Law, the steps the government ought to take to dispose of or eliminate hazardous materials have not been specified (Drenguis, 2014: 15). Similarly, Wang Jin, a professor at Peking University and an expert in environmental law, pointed out that Chinese laws look great at first glance, but are ineffective when it comes to their implementation (Wang, 2010). The ambiguities resulted in many counties and towns continuing to dispose waste without any treatment (Drenguis, 2014).

More recently, there has been growing attention to the problem of soil pollution, in particular in Hubei Province. In 2016, Wang Jianming, deputy director of Hubei Provincial People's Congress, expressed concerns that China has no specific legislation relating directly to soil protection, which limits the country's soil pollution control and prevention strategies (Zhou and Liu, 2016). Consequently, the 12th Hubei Provincial People's Congress passed the country's first set of regional laws and guidelines relating to soil pollution prevention. Shortly afterwards, China's 13th Five-Year Plan, published in March 2016, pledged that the country would give priority to cleaning up contaminated soil used in agriculture (Hou et al., 2017). It also promised to strengthen its soil pollution monitoring systems and promote new clean-up technologies (Stanway, 2016). According to Yuan Si, vice-chairman of the Environment Protection and Resources Conservation Committee (EPRCC) of the National People's Congress (NPC) Standing Committee, in 2017 a bill relating to soil pollution prevention will be introduced to the Standing Committee of the NPC (State Council, 2016b). He also emphasized the need for specific laws directed at soil contamination, because the lack of laws weakens the government's efforts to reduce soil contamination, which, in some parts of China, threatens water and food safety. Laws relating to the prevention of soil contamination will specify the division of responsibilities among government agencies, plans for establishing a survey and control system, and foster the allocation of larger amounts of monetary assistance, among other things (State Council, 2016b).

Soil Ten Plan

The "Soil Pollution Prevention and Remediation Action Plan" (also called Soil Ten Plan) was issued by the State Council on May 31, 2016 with the aim of comprehensively improving the quality of China's soils by the mid-21st century (State Council, 2016a). The plan aims to address five key tasks: "1) prioritizing the protection of arable lands, 2) controlling the sources of pollution, 3) assessing and managing polluted sites, 4) carrying out soil remediation methods on testing sites, and 5) strengthening the control and maintenance of the soil environment" (China Water Risk, 2014). The action plan lays out ten headline actions split into 35 categories and 231 specific points that should help to achieve the target of making 95 per cent of the currently contaminated land fit to reuse either for agricultural purposes or for new urban development. The action plan lists the following objectives (China Water Risk, 2016):

1. Key objectives & targets:

- To bring soil contamination under control by 2020, manage soil contamination hazards by 2030, and create a favourable ecological cycle by 2050;
- To ensure that over 90 per cent of the contaminated land can be utilized safely by 2020, and increase this rate to 95 per cent by 2030;

- Local governments need to finalize a detailed work plan and submit it to the group of ministries that developed the Plan by 2016;
- To set up national-level soil environmental quality monitoring points and monitoring networks by 2017;
- To set up soil environmental quality monitoring points to cover all the cities and counties by 2020;
- To establish laws and a regulation system related to soil pollution prevention and control by 2020.

2. Key pollutants to be monitored:

- Heavy metals: cadmium, mercury, arsenic, lead, and chromium;
- Organic pollutants: PAHs (Polycyclic aromatic hydrocarbons) and petroleum hydrocarbons.

3. Industrial pollution:

- To complete the investigation on the distribution and environmental impacts of contaminated industrial land use by key industries by 2020;
- By 2020, heavy metal emissions from key polluting industries should drop by 10 per cent from the 2013 level;
- To encourage the recycling of electronics, plastic, and packaging waste.

4. Agricultural pollution:

- To finalize the provincial soil remediation plan and the assessment methods of soil remediation efforts by 2017;
- To finalize the investigation of the total area of contaminated farmlands and the assessment of its impacts on agricultural products by 2018;
- To achieve zero increase of fertilizer and pesticide use in major crops. Effective utilization rates to reach 40 per cent and above. Coverage of fertilizer application based on soil sampling to reach 90 per cent and above by 2020;
- Over 75 per cent of large-scale livestock farms to be equipped with waste management facilities by 2020;
- Irrigation water to comply with farmland irrigation water quality standards (China Water Risk, 2016)

While the objectives are wide-ranging, many environmental experts and campaigners are disappointed about the lack of details in the document, claiming that it will be challenging to link the ultimate targets and the individual objectives of the plan, or to foresee from the specifications alone if the described targets would be reached. Chen Nengchang, a researcher at the Guangdong Institute of Eco-environment and Soil Sciences, said that no details have been provided on the standards that are going to be used to calculate the levels of contamination, what "safe to use" levels refer to, and if the implementation of the plan will be sufficient to achieve the targets (Zhang, 2016).

Environmentalist group Greenpeace also declared that additional legal measures need to be added to China's soil contamination action plan to make it more effective. China will set up a special fund dedicated to combating soil pollution, amounting to about CNY 5 trillion, based on its calculations of the average cost estimates in treating one hectare of land (Miranda, 2016). The action plan requires more financial input from the government, as well as the use of public-private partnerships, but the exact details on how this can be achieved and the private sector's contribution to the plan have yet to be clarified (Zhang, 2016). The government has set aside CNY 450 billion to tackle the multitude of problems with polluted soil (Li, 2016). However, the lack of laws and regulations may result in corruption and lead to the mismanagement of the massive investments into soil remediation.

Re-classification of soil use

In the Soil Ten Plan, agricultural soils are classified into three categories to maintain the safety of crops and livestock products: 1) non-contaminated and slightly contaminated soils, whose protection will be given priority, 2) mildly and moderately contaminated soils, which will be treated and classified as safe to use, and 3) severely contaminated soils, which will be brought under strict control (State Council, 2016a). By the end of 2017, "the technical guidelines for the categorization of the environmental quality of arable land will be released. By the end of 2020, arable land and agricultural products shall be concurrently monitored and evaluated based on a detailed survey of soil contamination, and such categorization will be promoted nationwide, starting with the pilot projects" (Soil Ten Plan, 2016: 9). While the plan aims to ensure a safe environment for agricultural production by categorizing agricultural land, issues of the reclassification of land go beyond agriculture.

In cities, many former industrial sites have been abandoned because of contamination concerns. Between 2001 and 2009, at least 98,000 industrial plants were closed and relocated across the country. Many of the industrial plants were highly polluting state-owned factories that were built during the Great Leap Forward (Drenguis, 2014). These former industrial zones have been re-classified for residential use, which poses health risks to both construction workers and the future residents. Besides, these health hazards of pollution are not limited to industrial land. Many real estate developers are hoping for the reclassification of contaminated farmlands so they can be used for non-agricultural purposes (He, 2014a). Although Chinese law requires the soil to be analyzed for contaminants before large construction projects commence, this requirement is generally ignored. One widely publicized case happened in 2007 in Wuhan (Hebei Province) after a former pesticide factory site was repurposed for residential use. Construction works were suspended after a worker suffered serious chemical poisoning.

Following the incident, the government was compelled to refund the purchase price of the building site, pay a CNY 130 million reimbursement to the development company, and spend nearly CNY 300 million to clean up the poisonous materials from the area (He, 2014a).

Identifying and monitoring the pollution sources

Identifying and controlling the major sources of pollution is the first step towards addressing the problem (State Council, 2016a). Between 2006 and 2010, the Ministry of Land and Resources (MLR) and the Ministry of Environmental Protection (MEP) carried out the most comprehensive survey of soil pollution in China. A statistical report of the quality of the nation's soil was published in 2014, in which 16 per cent of approximately 10,000 testing sites from 1,500 sampled areas were found to exceed the standards. However, the details of contaminated areas and the associated contaminants were never revealed. As a result, local governments, companies, and the general public are currently unaware of the severity of the country's soil pollution problem. In addition, some academics argue that the survey fails to reflect the real extent of pollution. According to the estimates of Gao Shengda, the editor of the website "China Environmental Remediation", the number of contaminated sites in China ranges between 300,000 and 500,000, which is 30-50 times the number of surveyed sites included in the 2014 report (Zhang, 2016).

In April 2016, hundreds of children at an elite private school in Changzhou, Jiangsu Province, fell ill after the opening of a new campus next to a former chemical plant site (Li, 2016). Following that incident, the first map of soil contamination conditions of the country was published by the IPE based on its pollution database, which identified 4,500 companies across 13 polluting industries, including the chemical, mining, and metal industries (Figure 1) (Zhang, 2016). The map showed that there were 3,998 state-controlled pollution sources and 502 non-state controlled ones. Besides, 729 chemical industrial parks were marked on the map (Zhang, 2016). The IPE also produced a map (Figure 2) of the level of *risk from soil contamination based on the location of 4,500 companies in key industries and over 700 industrial zones.*

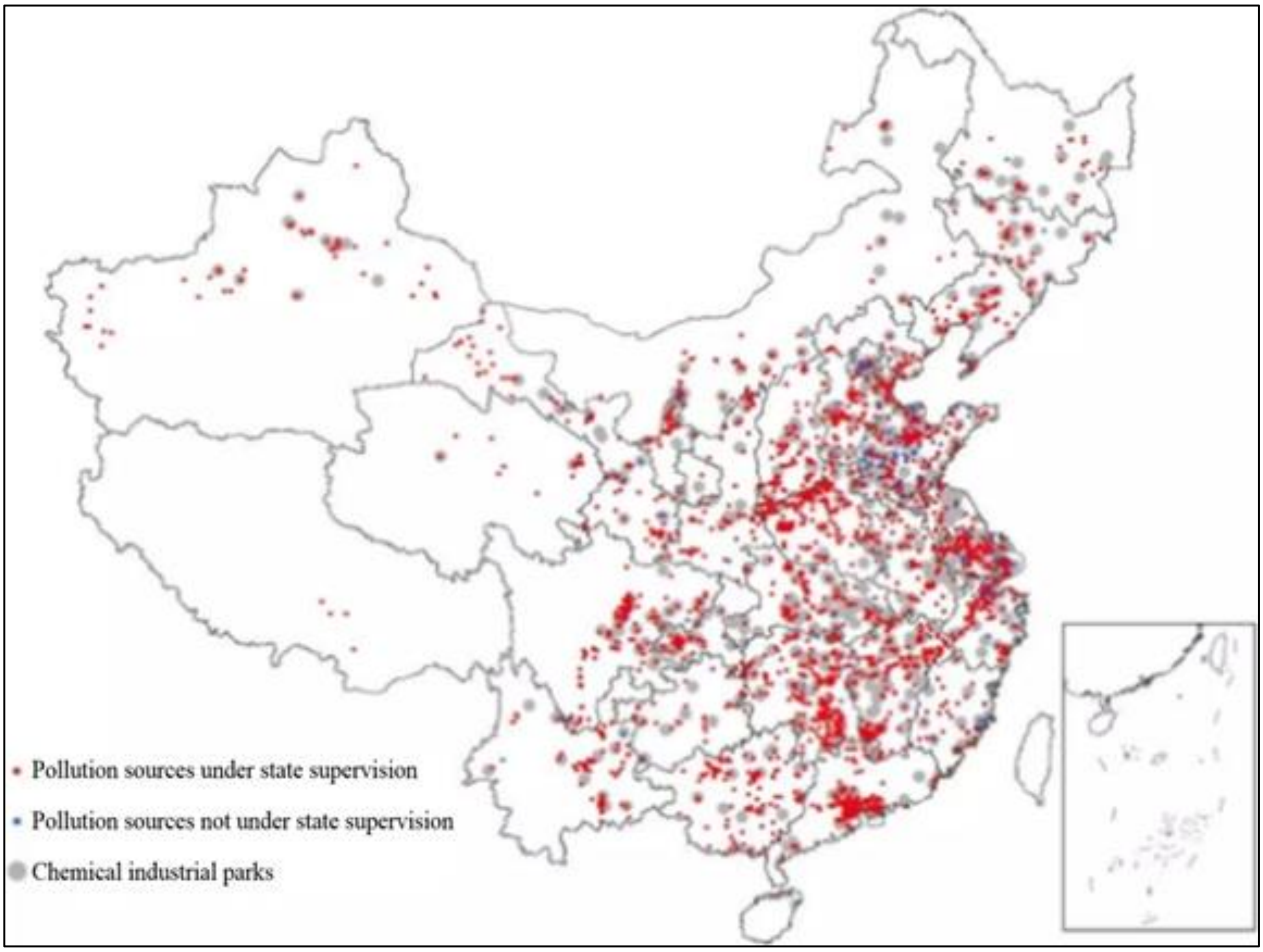

Figure 1: Location map of pollution sources
Source: Zhang (2016)

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Figure 2: Map of soil contamination risk based on the locations of 4,500 companies in key industries and over 700 industrial zones
Source: Zhang (2016)

According to the Soil Ten Plan, new surveys will be conducted to identify the sources of soil pollution and prevent the problem from worsening. By 2018, a new survey will identify the total areas polluted, the distribution of polluted farmland, and the impacts of soil pollution on agricultural products. On the other hand, by 2020, the location of and the environmental risks at key industrial sites will be ascertained. In addition, by 2020, a soil quality control system will be set up throughout China to monitor every region across the country. After that, a survey will be conducted every decade by the Ministry of Environmental Protection along with other government agencies (including the National Development and Reform Commission, the National Health and Family Planning Commission, the Ministry of Industry and Information Technology, the Ministry of Land and Resources, and the Ministry of Agriculture) to monitor the overall soil quality of China (Soil Ten Plan, 2016). In addition, the action plan includes provisions for better information sharing with the public. A comprehensive database will be established using data collected from the Ministry of Environmental Protection, the Ministry of Land and Resources, and the Ministry of Agriculture, and mobile internet tools will be deployed to receive data updates in real time (State Council, 2016a). However, even though government departments have set goals to build a database and give people access to information about soil conditions, the exact details of the information to be provided have not yet been specified.

Controlling the number of polluting enterprises

China's first officially accepted plan for controlling the heavy metal pollution of a specific area was implemented in the Xiangjiang River basin (Hunan Province) in 2011. Its goals were to halve the number of heavy-metal polluting enterprises in the Xiangjiang River basin by 2015 compared to the 2008 levels, to invest CNY 59.5 billion and complete 927 projects between 2012 and 2015 to control the industrial pollution in the area, and to decrease the amount of heavy metal emission by 50 per cent by 2015 (Hu et al., 2014). The plan failed: though pollution source reduction is a good way of controlling soil pollution, it is very difficult for the local governments to implement the policy because local governments depend on incomes from industries (He, 2014b). Furthermore, a change in the local GDP rather than a change in pollution levels is the most important indicator to evaluate the performance of local officials. Since farming can only generate low incomes in China, local officials are reluctant to close the larger, more profitable companies, even if they generate high levels of pollution.

The conflicts between the local government and local environmental-protection officials are also of great concern. In May 2010, six officials of the local Environmental Protection Bureau—including the bureau chief—were removed from office by the government of Guzhen County (Anhui Province), because they carried out three checks on a firm over a period of 20 days. The local government blamed the Environmental Protection Bureau officials for undermining their efforts to attract investors. According to a local law in Anhui Province, environmental authorities are required to obtain a permission before conducting checks, a policy that provides protection against unexpected checks to the largest energy consumers and polluters (Wang, 2010).

Similarly, Wong (2013) reports how in Hengyang (Hunan Province) a large heap of industrial waste has ruined farmlands and caused outraged comments from villagers on the internet. However, the factories are closely tied to government officials, and in the eyes of Hunan officials, the industries surrounding Hengyang are fundamental to maintaining Hunan's leading role in nonferrous metal production. The farmers do not expect to see improvements (Wong, 2013).

The Soil Ten Plan has set goals to strengthen the regulation on pollution sources. According to the plan, the government will "strictly implement the heavy metal pollutant emission standards […]; take stronger measures for the supervision and inspection of enterprises; and the […] enterprises that do not meet [the] standards after [they] have been updated will be suspended or permanently stopped" (Soil Ten Plan, 2016: 21). Considering the current situation of weak laws and enforcements, it is doubtful these goals will be fulfilled.

Promotion of technologies to reduce soil pollutants

Soil remediation projects are only beginning to be implemented. Liu Yangsheng, the secretary general of the Heavy Metals and Environmental Remediation Committee of China's Environmental Protection Industry Association, expressed his fear that the rehabilitation of heavy-metal polluted soil will be a long and slow process due to the ill-defined evaluation standards, rudimentary technology, and lack of funding. He also pointed out that costly techniques are unlikely to be widely adopted due to the magnitude of heavy metal contamination in the country. Also, overseas rehabilitation techniques that may be effective for small areas are not applicable to the vast polluted areas in China (He, 2014a). According to the Soil Ten Plan, 200 pilot projects will be launched to test soil pollution treatment and remediation technologies by the end of 2020. Once the pilot projects are completed, the results will be evaluated, and the best technologies will be selected (Drenguis, 2014). Both chemical and biological approaches may be used.

Chemical approaches

In China, the most commonly used chemical strategy to reduce the amounts of heavy metals absorbed by plants is liming. Liming is the application of calcium- and magnesium-rich materials which neutralize soil acidity and increase the activity of soil bacteria (Tyler and Olsson, 2001). Liming also manipulates the phytoavailability of metals, reducing the amount of metals that is taken up by the plant (Zhao et al., 2014). The technique of liming acidic soils should be applied particularly on lands heavily polluted by high-risk contaminants, such as Cd and Pb. When lime is applied to the soil, the heavy metal pollutants will oxidize, which lessens the chances of the plant roots absorbing them (Stanway, 2014). There are a variety of liming materials on the market with different reaction rates, acid neutralizing capacities, and costs. The application of several rounds of liming material over successive crop seasons may increase the pH to the desired level, but its over-application may also result in harm to plant life (Zhao et al., 2014).

Biological approaches

There are also biological methods for soil remediation. For example, the metal pollutants can be detoxified using microorganisms to transform their valences, precipitate chemicals outside of the cells, or enzymatically reduce metals by metabolic processes, rather than absorb them. An alternative method is phytoremediation: the planting of specific plants such as willows, birches, and leguminous plants, which absorb and remove the pollutants from the soil. The plants can then be harvested, processed and disposed of. Besides being cheaper than physicochemical procedures, this approach also has the advantage of permanently removing the pollutants from the soil. However, for such methods to be applicable to the vast areas of polluted agricultural soils in China, they need to be both efficient and cost-effective, because farmers can neither afford to invest in expensive soil remediation techniques nor suspend their farming activities for years (Lone et al., 2008). As Chen Nengchang, a soil remediation specialist at the Guangdong Institute of Eco-Environment and Soil Sciences explains, cultivating non-food grains would clean the soil over time. However, producing sufficient grain for its large and growing population is of prime concern to the government, so shifting to the production of non-food grains is only proposed for the more heavily polluted soils (He, 2014a).

According to He (2014a), the Foshan Jinkuizi Plant Nutrition Company has pioneered a technique for soil remediation with the specific purpose of rehabilitating China's heavy metal-contaminated soils. The company has developed a microorganism capable of changing the ionic property of heavy metals in the soil, thus deactivating the contaminants. The company argues that their technique is cost-efficient, easy to use, its application does not create secondary pollutants, and is already available in commercial form. In another possible breakthrough, the Guangdong Geoanalysis Research Center has developed a new material, Mont-SH6, which it claims is capable of absorbing heavy metal pollutants such as lead, cadmium, zinc, mercury, and copper. According to Liu Wenhua, chief engineer at the research center, the new product is capable of reducing the cadmium levels of the soil by more than 90 per cent, and the material's cost of production is low: the remediation process for 0.6 ha of cadmium-polluted rice fields would cost about CNY 33,000. However, according to Liu, mass production could reduce these costs to CNY 2,200-3,300 (He, 2014a).

Although experiments with micro-organisms and plants that are capable of absorbing soil pollutants are promising, it is questionable how effective they will be, given the extent of the problem (Stanway, 2014). Also, there isn't a universal solution for the country's polluted soils. For example, a species of Indian mustard has been shown to be effective in absorbing selenium, and Chinese ferns can accumulate arsenic, but they have little impact on other pollutants.

Challenges

The central government has shown a strong determination to address China's issues of soil pollution, however, significant results are yet to be seen (Kong, 2015). Disagreements between local governments are one reason for the delay of a nationwide policy. Unlike air and water pollution, soil pollution can be more effectively tackled with regional strategies than through an overarching national approach. The geological properties of soil differ from region to region, and local authorities must figure out the most suitable strategies for the local conditions. For instance, some areas might naturally have higher concentrations of metals, in which case a better way to mitigate risk is to ensure the land is used appropriately, rather than through soil remediation. Moreover, unlike air and water, soil does not travel, which means that provincial governments can manage their own soil without the need for cross-border coordination. Also, the heavy reliance of soil management policies on researchers, laboratories, and equipment can most easily be met by provincial-level governments (Kong, 2015).

Indeed, some scholars argued that regionally implemented policies can more efficiently meet the needs of China's cities and provinces, compared to top-down political directives. Shanghai was the first local government to establish its own soil policy. The city developed its clean soil standards in 2007 in the run-up to the World Expo 2010. This set of standards has since become a valuable reference for other cities, indicating that the central government should provide stronger incentives to selected provincial governments to develop their own strategies and become pioneers in soil protection policies. By focusing investment on a couple of selected provinces, relevant skills and mechanisms can be developed more efficiently (Kong, 2015).

Apart from the difficulty in implementing uniform policies across local governments, experts in the field suggest that technical barriers have been a major hindrance for provincial governments. There are various contaminants, including heavy metals like cadmium or lead, volatile organic compounds (VOCs) such as benzene, persistent organic pollutants (POPs) coming from different chemicals and pesticides, and waste left by fossil fuel combustion. All these pollutants require different techniques to be removed from the soil. Besides, many local institutions are confused about clean soil standards, the right technology for soil inspection and treatment, and management strategies for vast areas of land. Local governments may need more guidance from the central government to overcome such barriers (Kong, 2015).

Besides the technological and legislative challenges, the biggest difficulty is the funding of soil remediation projects. The costs of cleaning up the polluted land are indeed staggering. In 2015, the central government assigned a budget of CNY 2.8 billion for anti-pollution programs across 30 prefecture-level cities, but experts claim this amount is far from sufficient. According to Lan Hong, an professor at Renmin University, "even with cheap restoration methods, it would take CNY 300,000 per hectare of land polluted by heavy metals, which means at least CNY 6 trillion is needed" (Deng and Leng, 2016). On the other hand, the Jiangsu Institute of Environmental Industry estimated that China's soil remediation industry is a market that could reach CNY 757 billion between 2014 and 2020, financed almost entirely by government subsidies (He, 2014a). Zhuang Guotai, the head of the Ministry of Environmental Protection's Department of Nature and Ecology Conservation estimated that the total cleanup costs could eventually reach CNY 11 trillion. Although there are some available remediation techniques, the country needs more low-cost technologies to tackle a problem of this magnitude (Stanway, 2014).

While investors can impose a fee for cleaned wastewater, it is difficult to do so for clean soil, so there is the potential for only a small cost recovery from soil rehabilitation. The involvement of developers who are interested to clean up polluted urban sites could mean a possible funding solution, but this possibility has had limited results so far (Hornby, 2015). This raises the problem of obtaining private funds for soil rehabilitation.

Wangxia Hui, one of the MEP directors, pointed out that until now the responsibility of the parties joining forces against soil pollution has not been clarified. Soil pollution prevention and control is one of the responsibilities of many different government departments, including environmental protection, development and reform, science and technology, finance, land, housing construction, and agriculture, but there has not yet been a good mechanism for all these parties to work together. For example, when preparing an urban and rural development plan, most local planning authorities do not give soil quality sufficient consideration. Finally, public participation in soil protection is limited due to the lack of appropriate mechanisms for the public to know the extent of soil pollution (Guo and Dai, 2016).

Conclusions

Soil pollution is the outcome of various natural factors and human activities that result from people's inadequate use of land resources and the "grow first, clean up later" attitude prevalent in China (Currell, 2013). This attitude is proving very expensive now that soil pollution has reached critical levels. Chinese people are concerned about the quality of the food, and China is forced to import food from other countries. Efforts to restore and clean up the soil are underway, but it is an expensive and time-consuming process.

Soil pollution is different from soil degradation in that it is more difficult to identify, it is directly related to economic activities (whether the excessive use of pesticides, or industrial emissions), and it is more expensive to remediate. China's rapid economic growth and disregard for its environmental problems, partly originating from China's desire to put an end to poverty, and partly on the assumption that the inflicted damage could be repaired later at a relatively cheap cost, has resulted in about one-fifth of the country's cropland already severely contaminated. The Chinese government has finally decided that the "clean up later" period has arrived, and China's State Council has recently instructed that over 90 per cent of the contaminated land should be safe to use by 2020, and 95 per cent by 2030, as part of the Soil Ten Plan.

A further problem which prevents soil pollution from being easily tackled is that on the one hand, soil pollution is a direct result of air emissions from manufacturing industries, so emissions have to be curbed by regulating and, if necessary, fining or closing these industries. On the other hand, these same manufacturing industries provide the bulk of the taxation to the local governments, so a threat of leaving the area if regulated or fined may stop the local governments from acting. Furthermore, if the companies actually do close, the government may be starved of the funds needed to clean up the pollution, and the companies may just open in other provinces with less stringent standards. These are clear contradictions that may prevent a successful outcome of the government's soil rehabilitation efforts. Nevertheless, the regulations reflect the country's determination to finally address its soil pollution problems. If the central government provides enough financial support and establishes and enforces concomitant laws, the goals would likely be achieved (Deng and Leng, 2016).

References

China Water Risk (2014). Soil Pollution Standards & Proposed Law. Retrieved 15 December 2016 from http://chinawaterrisk.org/notices/new-soil-pollution-standards/

China Water Risk (2016). New 'Soil Ten Plan' To Safeguard China's Food Safety & Healthy Living Environment. Retrieved 15 December 2016 from http://chinawaterrisk.org/notices/new-soil-ten-plan-to-safeguard-chinas-food-safety-healthy-living-environment/

Currell M. (December, 2013). Shanghai's 'airpocalypse': can China fix its deadly pollution? Retrieved 15 December 2016 from http://theconversation.com/shanghais-airpocalypse-can-china-fix-its-deadly-pollution-21275

Delang, C.O. (2016a) *China's Water Pollution Problems*. London: Routledge

Delang, C.O. (2016b) *China's Air Pollution Problems*. London: Routledge

Deng L., Shangguan Z.P. & Li, R. (2012). Effects of the grain-for-green program on soil erosion in China. *International Journal of Sediment Research* 27(1), 131-138.

Deng X.C. & Leng S.M. (June, 2016). China determined to clean up 90% of polluted arable land by 2020. Global Times Retrieved 15 December 2016 from http://www.globaltimes.cn/content/986279.shtml

Drenguis D.D. (2014). Reap What You Sow: Soil Pollution Remediation Reform in China. *Pacific Rim Law & Policy Journal Association* 23, 171

Guo Xi & Dai Yu. (May, 2016). Soil pollution control what Difficulties children? Expert: weak infrastructure, backward legislation, unclear responsibilities. Retrieved 15 December 2016 from http://www.top-news.top/news-12153368.html

He G. (July, 2014a). The Soil Pollution Crisis in China: A Cleanup Presents Daunting Challenge. Environment 360. Retrieved 15 December 2016 from http://e360.yale.edu/feature/the_soil_pollution_crisis_in_china_a_cleanup_presents_daunting_challenge/2786/

He G. (July, 2014b). In China's Heartland, A Toxic Trail Leads from Factories to Fields to Food. Environment 360. Retrieved 15 December 2016 from http://e360.yale.edu/feature/chinas_toxic_trail_leads_from_factories_to_food/2784/

He G. (July, 2014c). China's Dirty Pollution Secret: The Boom Poisoned Its Soil and Crops. Environment 360. Retrieved 15 December 2016 from http://e360.yale.edu/feature/chinas_dirty_pollution_secret_the_boom_poisoned_its_soil_and_crops/2782/

Hornby L. (September, 2015). Chinese environment: Ground operation. Financial Times. Retrieved 15 December 2016 from https://www.ft.com/content/d096f594-4be0-11e5-b558-8a9722977189

Hou, D., Ding, Z., Li, G., Wu, L., Hu, P., Guo, G., ... & Wang, X. (2017). A sustainability assessment framework for agricultural land remediation in China. *Land Degradation & Development*.

Hu H., Jin Q. & Kavan P. (2014). A Study of Heavy Metal Pollution in China: Current Status, Pollution-Control Policies and Countermeasures. *Sustainability* 6, 5820-5838; doi:10.3390/su6095820

Kong A.. (May, 2015). No quick fix for China's polluted soil. South China Morning Post. Retrieved 15 December 2016 from http://www.scmp.com/comment/insight-opinion/article/1783358/no-quick-fix-chinas-polluted-soil

Lone M.L., He Z.L., Stoffella P.J. & Yang X.E. (2008). Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. *Journal of Zhejiang University Science B*, *9*(3), 210-220. Retrieved 15 December 2016 from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2266886/

Miranda E. (June, 2016). Greenpeace to China: Give Soil Pollution Action Plan 'Teeth', Add Legal Measures. Yibada. Retrieved 15 December 2016 from http://en.yibada.com/articles/128323/20160602/greenpeace-to-china-give-soil-pollution-action-plan-teeth-add-legal-measures.htm#ixzz4HrhhUfFX

Mu Z.L., Bu S.C. & Xue B. (2014). Environmental Legislation in China: Achievements, Challenges and Trends. *Sustainability*, 6, 8967-8979; doi:10.3390/su6128967

Soil Ten Plan (2016). Action Plan for Prevention and Control of Soil Pollution. Danish Soil Partnership Retrieved 15 December 2016 from http://danishsoil.org/media/test_sites/uploads/Soil%20Ten%20Plan.pdf

Stanway, D. (September, 2014). FACTBOX-Solutions to China's soil contamination crisis. Reuters. Retrieved from http://uk.reuters.com/article/china-pollution-technology-idUKL3N0QZ2CL20140916

Stanway, D. (May, 2016). China releases new action plan to tackle soil pollution. Reuters. Retrieved from http://www.reuters.com/article/us-china-environment-soil-idUSKCN0YM0YO

State Council. (May, 2016a). Efforts to prevent and remedy soil pollution. Beijing: The State Council of the People's Republic Of China. Retrieved 15 December 2016 from http://english.gov.cn/policies/latest_releases/2016/05/31/content_281475361737430.htm

State Council. (March, 2016b). China working on law to tackle soil pollution. Beijing: The State Council of People's Republic of China. Retrieved 15 December 2016 from http://english.gov.cn/news/top_news/2016/03/10/content_281475304770375.htm

Tyler, G., & Olsson, T. (2001). Plant uptake of major and minor mineral elements as influenced by soil acidity and liming. *Plant and Soil*, *230*(2), 307-321.

Wang J. (September, 2010). "China's green laws are useless". China Dialogue. Retrieved 15 December 2016from https://www.chinadialogue.net/article/show/single/en/3831

Wong E. (December, 2013). Pollution Rising, Chinese Fear for Soil and Food. New York Times. Retrieved 15 December 2016 from http://www.nytimes.com/2013/12/31/world/asia/good-earth-no-more-soil-pollution-plagues-chinese-countryside.html?_r=0

Wong, E. (2014). One-Fifth of China's Farmland Is Polluted, State Study Finds. The New York Times. Retrieved from http://www.nytimes.com/2014/04/18/world/asia/one-fifth-of-chinas-farmland-is-polluted-state-report-finds.html?hpw&rref=science&_r=1

Zhang C. (June, 2016). Lack of data, openness could obstruct soil clean up. Earth Journalism Network. Retrieved from http://earthjournalism.net/stories/lack-of-data-openness-could-obstruct-soil-clean-up

Zhao F.J., Ma Y.B., Zhu Y.G., Tang Z. & McGrath S.P. (2014) Soil Contamination in China: Current Status and Mitigation Strategies. American Chemical Society. *Environmental science & technology*, *49*(2), 750-759

Zhou L. & Liu K. (February, 2016). China's first soil pollution prevention regulations introduced. China Daily. Retrieved 15 December 2016 from http://www.chinadaily.com.cn/china/2016-02/01/content_23348053.htm

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Lateral Migration of the Jiu River Course between 1864 and 2018. Case study: Craiova – Zăval sector

Andreea-Gabriela ZAMFIR[1,*], Claudia Daniela ALBĂ[1], Sandu BOENGIU[1]

[1] Faculty of SCIENCE, Department of GEOGRAPHY, University of CRAIOVA, A.I.Cuza, nr.13, 200585, Craiova, Romania

* *Corresponding author*: andreeaz2004@yahoo.com

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Abstract

In the last 154 years the Jiu river course from its confluence with Amaradia till the outlet, has undergone through serious lateral and length changes. The main purpose of this article is to highlight these changes and determine their magnitude and also to understand the future evolution of the Jiu course.
The results of our analysis showed that from 1864 until 2018 the Jiu river became shorter in the lower section, decreasing with 38.1 km, from 134 km to 95.9 km. Shortening of the course happened gradually. Thus, between 1864 and 1910, the length of the course decreased by 25.6 km, from 134 km to 108.4 km. From 1910 until 1970 there was a shortening of 11.9 km and between 1970 and 2018, the river shortened its course by about 0.6 km. The greatest lateral distance between its historical and present channels showed a maximum of 11.22 km on the outlet.

Keywords: *Jiu, levee, neotectonic movements, coefficient of sinuosity, lateral migration*

Rezumat. Migrarea laterală a cursului Jiului între 1864 și 2018. Studiu de caz: sectorul Craiova - Zăval

În ultimii 154 de ani cursul Jiului de la confluența cu Amaradia și până la vărsarea în Dunăre a suferit modificări laterale și de lungime. Scopul prezentului articol este acela de a evidenția aceste modificări și de a le stabili amploarea, cu desprinderea unor concluzii legate de viitoarea evoluție a cursului Jiului. Rezultatele analizei suporturilor cartografice au arătat că din 1864 și până în 2018 Jiul s-a scurtat în secțiunea inferioară cu 38,1 km, scăzând de la 134 de km la 95,9 km. Scurtarea cursului s-a realizat treptat. Astfel, între 1864 și 1910 lungimea cursului a scăzut cu 25,6 km, de la 134 km până la 108,4 km. Din 1910 și până în 1970 s-a mai produs o scurtare cu 11,9 km, iar între 1970 și 2018, Jiul şi-a scurtat cursul cu aproximativ 0,6 km. Cea mai mare distanță dintre cursul istoric și cel prezent indică o valoare de 11.22 km la vărsarea în Dunăre.

Cuvinte-cheie: *Jiu, diguri, mișcări neotectonice, coeficient de sinuozitate, migrare laterală*

Introduction

Scientifical research about how the rivers “behave” started to appear along with the raising of Fluvial Geomorphology, at the half of the XIX century. Wolman and Leopold published in 1957 the paper: ”River Channel Patterns - Braided, Meandering and Straight” in which they were concerned with channel pattern. Later, in 1977 James Brice wrote the paper: ”Lateral Migration of the Middle Sacramento River, California, where he extracted from topographic maps and aerial photographs the centerlines of the Sacramento river to a specific time. Then, he made an analysis of the channel form and its migration.

Rhoads and Welford tried to explain in 1991 why the rivers meander, i.e. migrate to lateral, and they wrote the paper: ”Initiation of River Mandering” giving a series of hypothesis such as: Coriolis force, Bar Theory and Bend Theory (Hooke, 2013).

Of course, there are plenty of scientific papers trying to explain rivers lateral migration, why they are creating meanders, always changing the morphology of the floodplains. Even in the Romanian literature there are some scientific papers concerned with fluvial systems and their evolution during time. In Romania, Rădoane et al wrote in 2013 ”River channel planform changes based on successive cartographic data”. The analysed rivers were Moldova and Someșul Mic.

Related strictly to the Jiu river, Ionuș (2013), wrote: ”Preliminary data on the Jiu River meanders in the lower course (South-West Romania)”. This paper is a complex study about Jiu river bed in terms of geometry and complexity of meanders in its lower sector.

Traying to explaian how the things work and why the rivers are creating meanders, we have to see the situation to a bigger scale and maybe to apply it to ours. Some authors which have studied the problem, the most prestigious being Rhoads and Welford (1991), found out that the major arguments that have been used over time to explain why rivers meander are: Coriolis force, energy arguments (excess, minimization), bank erosion and sediment effect, helical and secondary flows, inherent property of turbulent flow, interaction between flow and mobile channel, bar theory and bend theory (Rhoads and Welford, 1991).

Coriolis force is the force associated with Earth’s rotation and it moves objects to the right in the northern hemisphere, especially rivers, eroding the right-hand channel banks. Jiu flows through the northen emisphere, thus we used this concept to explain if it has an impact on meander formation and it was proved that Coriolis force associated with erosion are producing secondary currents, but it doesn't have the magnitude to cause significant deformation of the channel (Rhoads and Welford, 1991).

Bar theory suggest that: "deformation of the channel bed is the fundamental cause of meandering", (Callander, 1978), alternate bars developing prior to the initiation of channel curvature, but this theory has major limitations, because, as it was explained, it assumes that channel banks are inerodible and thus does not incorporate a mechanism for the initiation of channel curvature. (Rhoads and Welford, 1991).

Considered one of the biggest river from south-west of Romania, the Jiu river has its springs in Southern Carpathians and after 339 km it reaches to the Danube (Atlasul Cadastrului Apelor din România, 1992). In the upper course, Jiu river seems to be more stable, but while it flows towards is lowest point the situation change drastically, and what we want is to undersatand why this is happening.

The analyzed river section starts North of Craiova city at 23°42'26.436"E and 44°21'57.61"N and ends South of Zăval village, at 23°48'41.115"E and 43°46'48.409"N.

This section corresponds to a part of the Jiu middle course, which flows through the South part of the Getic Piedmont, but the interest of the research goes especially to the lower course, which crosses the central axis of the Oltenia Plain.

Some can observe that in its lower section the Jiu river has created meanders and from place to place it course is braided. But the most impressive thing is that the Jiu moved its riverbed many times. By analysing the pattern in its evolution we want to answer to some questions: "why those things happened? why the Jiu river meanders an moves its course? can we predict its future evolution?".

Method

The Jiu river fluctuation over time were identified based on four cartographic supports. Therefore, we used the following maps: Szathmári's Map of Southern Romania (Charta României Meridionale, 1864), sheets IV – 7 and IV – 8, at scale 1:57.600, georeferenced in the STEREO_70 projection system. The second map was an Austrian map from 1910, at scale 1:200.000, also projected in STEREO_70. The third map correspond to the Soviet maps sheets: L-34-132-C, L-34-144-B, L-34-144-A, from 1970, at scale 1:50.000. Those map sheets were georeferenced in the STEREO_70 projection system. For 2018 we used an Open Street Map sheet, which is an open source data project. The main operations were to extract by vectorization the Jiu historical and present channels and to create a GIS database in order to to facilitate measurements, ordering and comparisons. We have also calculated the distance between the Jiu river channels from 1864 to 2018 in 41 sections, chosen after we analyzed the cartographic data. To understand that the lateral migration of the Jiu river had an impact on its length, we calculated the sinuosity coefficient in order to identify what type of channel Jiu river has and to catch its main evolution tendencies. The mathematical formula for calculating this coefficient (Cs) involves dividing the real length of the river course (Rl), between two points, to the straight-line length (Stl) between the these points ($Cs = Rl/Stl$). Values less than 1.5 suggest that the river sector is sinuous and values greater than or equal to 1.5 are associated with the meandered river sectors (Leopold, Wolman, 1957).

Results and Discussion

This Jiu river's section is one of the most dynamic, suffering from intense lateral oscillations over time, with an impact on the morphology of the floodplain that the river crosses, as well as on the agricultural practices. The late antropic intervention on the course allowed to the Jiu river to travel freely through its floodplain. Its lateral migration was also possible due to the small slope of the thalweg, or beause of the neotectonic movements and the meteo-hydrological events. Of course, the transported sediments and the banks resistance to erosion played a key role in Jiu's evolution. Another possible explanation of Jiu lateral oscillation is related to the alluvial fans, created by the tributary streams, which are pushing aside the main channel. This situation happenes when Dâlga stream flows into the Jiu river, bending its course (Boengiu et al, 2011).

The analysis we carried out revealed that there were some changes in length between Jiu-Amaradia and Jiu-Danube confluences. If in 1864, the straight line between the two outlets was 70.3 km, in 2018 the distance has decreased to 65.3 km.

The changing of the length of the Jiu course, in the sense of decreasing, was a consequence of river rectification, a situation highlighted by the values of the sinuosity coefficient. The obtained value showed that sinuosity coefficient dropped from 1.91 in 1864 to 1.55 in 1910. In 1970 the sinuosity coefficient was 1.47, value registered also in 2018. Leopold and Wolman suggested in 1957 that values less than 1.5 are specific to a sinuous rivers and values greater than or equal to 1.5 are associated with the meandered bedside sectors. Therefore, Jiu river evolved from a meandered bed in 1864 to a sinuous one in 2018.

The course of the Jiu, during the analyzed period, suffered visible lateral changes (Fig. 1).

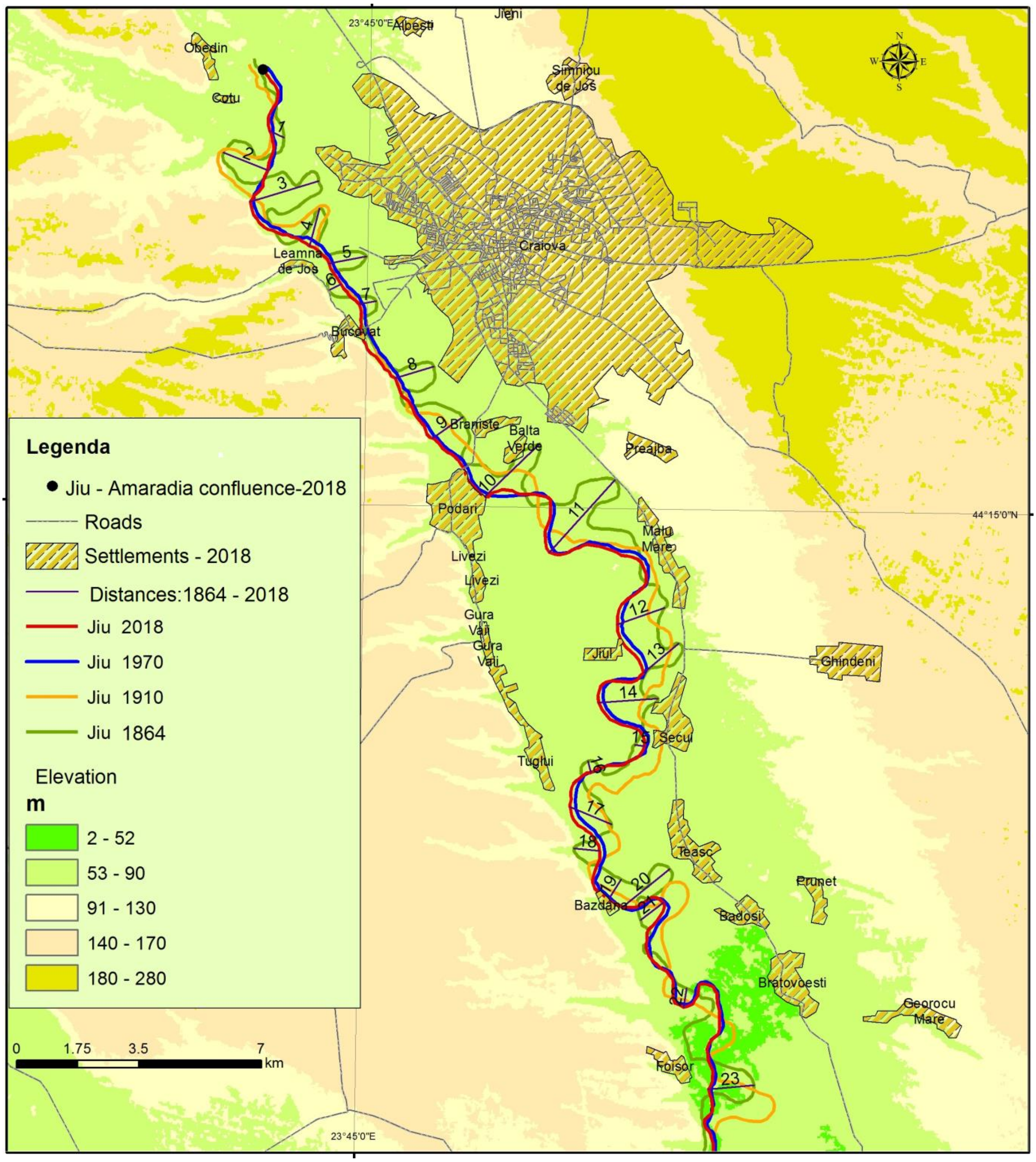

Fig. 1: Jiu river changing between 1864 and 2018: a –Amaradia – Foișor sector

In order to highlight these changes, distance measurements between the Jiu course from 1864 and 2018 were made in 41 sections (Table 1).

In the section between Breasta and Bucovăţ, more precisely near the Roșieni village, the Jiu course suffered between 1864 and 2018 a lateral modification of 2.04 km. An approximately equal distance (2.1 km) was also measured near Podari hydrometric station. Between Podari and Malu Mare, the Jiu river migrated 2.8 km from East to West. In the Jiul village (also known as Vîrâţi), located just 300 m from the river bank, the Jiu river migration occurred on a distance of 1.44 km from East to West. Between the settlements of Secui and Ţugului, the migration of the river on a distance of 1.7 km from East to West forced the inhabitants of the second village to move their houses from the immediate vicinity of the minor bed of the Jiu river at a distance ranging from 700 m to 3 km from the current river bed.

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Table 1: The distances between Jiu river's channels from 1864 and 2018 and medium slope

Section	Dist. km	Slope (º)	Section	Dist. km	Slope (º)
1	0.44	9.38	22	0.56	2.50
2	1.37	2.84	23	1.31	4.89
3	2.04	5.68	24	0.72	3.30
4	1.11	2.65	25	1.86	5.73
5	1.08	2.59	26	1.14	2.73
6	0.40	3.84	27	1.77	3.88
7	0.50	2.86	28	0.68	6.42
8	1.15	3.28	29	0.59	3.04
9	1.06	3.61	30	0.70	5.11
10	2.10	2.18	31	0.49	5.29
11	2.80	3.31	32	0.50	5.44
12	1.44	4.27	33	0.73	6.04
13	1.31	4.48	34	0.82	4.35
14	1.70	4.64	35	1.29	1.67
15	0.27	4.35	36	0.45	4.12
16	0.34	2.16	37	0.46	6.20
17	1.28	3.63	38	5.32	3.98
18	0.73	3.88	39	5.56	4.44
19	0.69	5.73	40	6.45	3.45
20	1.73	5.36	41	11.22	2.55
21	0.83	3.81			

South of Foişor, a village located within Drănic commune, the meander that existed in 1864 was cut and the Jiu river became more straight-lined, migrating 1.31 km from East to West (Fig.1).

In the vicinity of the villages Drănic and Padea, the Jiu river did not turn its stream, and it still has a very strong meandering course, the wave length of the meanders varying from 2826 m to 2879 m and the amplitude of the meanders also varies from 1855 m to 633 m (Ionuș, 2013). The distance within meander curvature that existed in 1864 and the current one varies between 1.14 km and 1.86 km

Beyond the cartographic evidence that the Jiu river has changed its course, a number of abandoned meanders can be seen on the terrain, such as those from Popoveni, Malu Mare, Podari, Bratovoeşti - Rojişte, between Tâmbureşti and Căciulăteşti, Sadova etc. The sectors between past and present courses are covered with a dense floodplain vegetation.

Changes in the course of the Jiu in the section from the confluence with Amaradia to the Danube were caused, among other factors, by the low water velocity (below 1 m / sec) and by the decreasing slope. It was noted that as the slope decreased, the distance between the 1864 and the 2018 course increased (Table 1).

We have also calculated the annual migration rate (Fig. 2) by dividing the migration amount by the number of years in the time period (154 years).

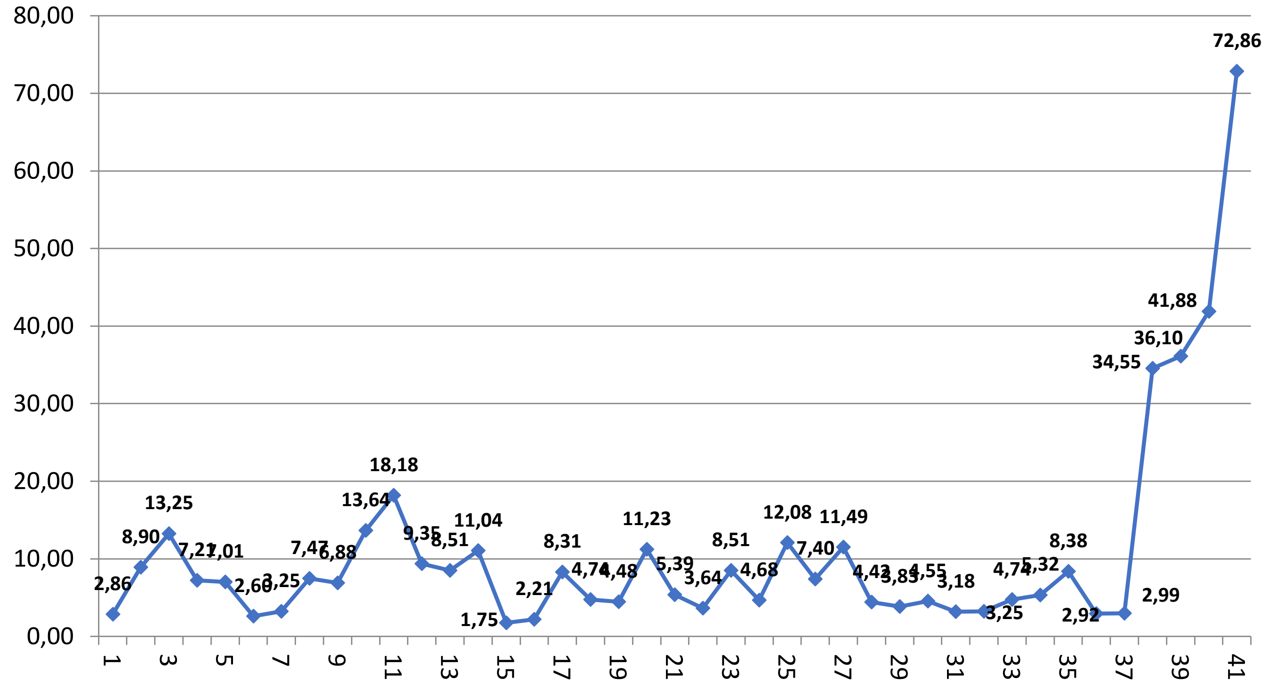

Fig. 2: Migration rate (m/yr)

The migration rate was measured in meters per year and the biggest value corresponds to the last section. Here the migration rate was 72 m/year. High migration rates have been recorded in the 38th, 39th and 40th sections. In this sections the lateral migration rate per year was above 34m/yr. Those section corresponds the the lower sector of the Jiu river course. High migration rate were registered at Podari and on the line between Podari and Preajba (18.1 m/yr). From the 28th to the 37th section the lateral migration rate per year was less than 8m/yr, with the lowest value of 2,29 m/yr registered south of Gângiova. The lowest migration rate was recorded near Secui village, and it was less than 2 m/yr (1.75 m/yr).

As the Jiu river flows towards the Danube, the distance between its channel from 1864 and 2018 increases. Thus, from the south of Gângiova, the difference between the two channels gradually increases from 460 m to 11.22 km in the confluence area with the Danube (Fig. 3).

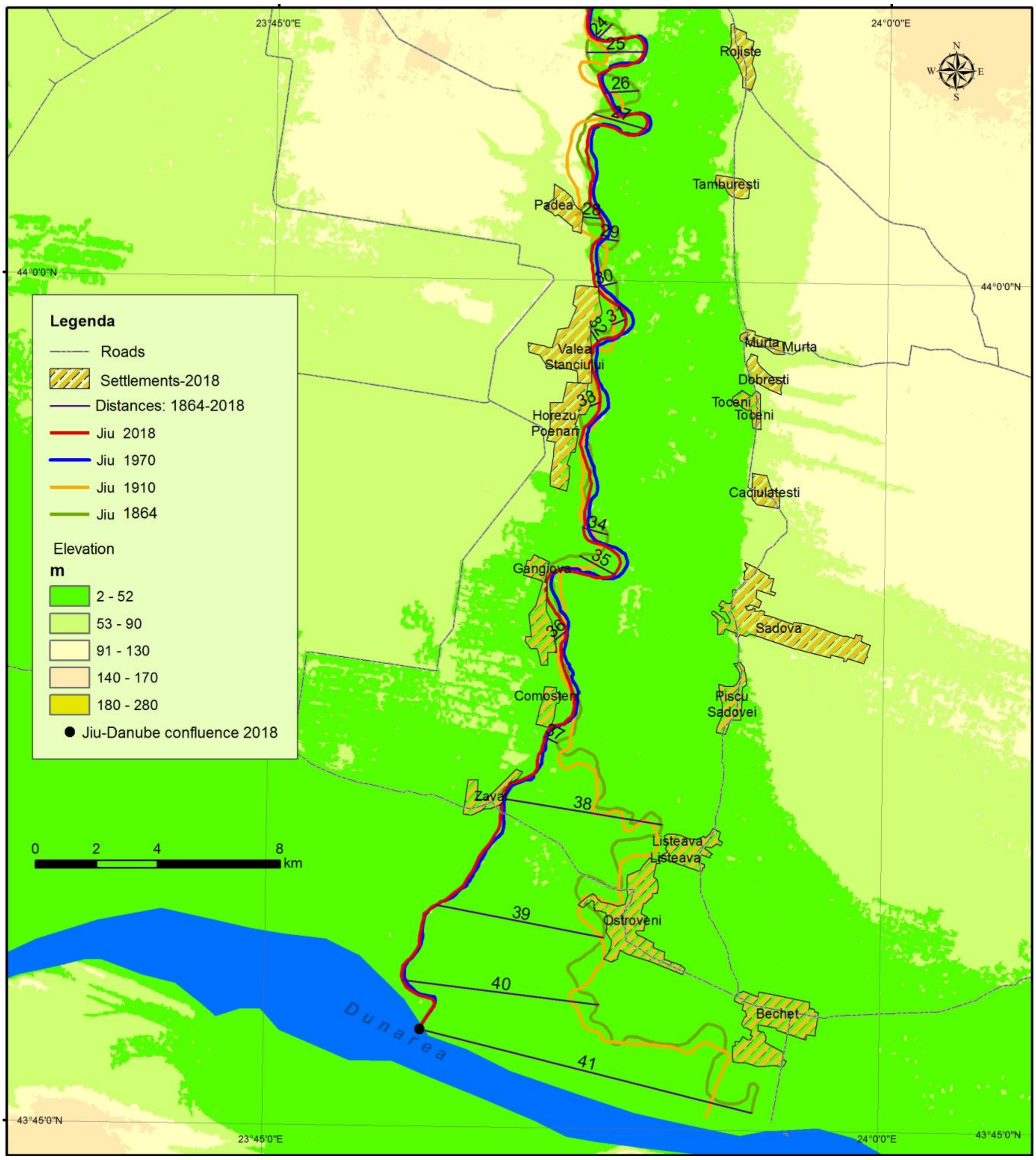

Fig. 3: Jiu river channel migration between Gângiova and Danube confluence – 1864 - 2018

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The sandy bottom of the bed, its too wide breadth, as well as the spring and autumn high waters were considered responsible for the course change (Nicolescu, 1932).

By doing an analysis of the Jiu course, Nicolescu identified in 1932 four stages in its evolution until then. Chronologically, a first course was the one under the terrace on the left, which remained in the literature under the name of "Jiul Bătrân" (Old Jiu), and could be seen from the south of Craiova until the outlet. Then followed the Jieț phase, when the Jiu river was flowing along the line of Murta, Dobreşti, Căciulăteşti, Sadova, Lişteava, Ostroveni and Bechet. Jieț separated from Jiu and now it flows parallel with it from Murta to the Danube. The next phase indicates a Jiu that discharged into the Danube near Bechet, but passed through the commune of Comoșteni and Grindeni. The last phase is that of the Jiu flowing under the right slope, spilling into the Danube near Copanița islet, approximately halfway between the confluence of 1864 and 2018 (Nicolescu, 1932).

Jiu's clear tendency to build its floodplain on the left side and to destroy the right bank through lateral erosion or even regressive erosion on some portions is another proof that Jiu has turned strongly westward (Coteț, 1957).

In an attempt to determine the causes of Jiu's course changes, Nicolescu (1932) questioned the following situation: Jiu was bound by a system of lakes and ponds from the Nedeia (on the right bank of the Jiu) and the Potel (left of Jiu) lakes. Jiu was filling up these lakes, but as much water as it could send to them, they dried out regularly and alternatively. Nedeia lake dried out near the Jiu and increased on the opposite side, and the Potel pond was increasing in the Jiu side and dropped to the opposite side. The author mentioned above said that in some years the situation was going backwards. The phenomena of drying and increasing the water level of the ponds were closely related to the oscillations of the Jiu river bed to the East and West (Nicolescu, 1932). Taking on the ideas of Murgoci, Martonne, Mrazec, Matheiu Draghiceanu and Ionescu Argetoaia, Nicolescu suggested that changes of the Jiu course and also of the entire hydrographic network of Oltenia, were due to the presence of the neotectonic movements (Nicolescu, 1932).

The reactivation of the neotectonic movements in the Pasadena phase, the Pleistocene Medium, reactivated the ascension of the Balş-Leu-Rotunda line, which forced Jiu to deviate south and indicate a slow tendency of deviation to the southwest, the proof being the course from present and development of its floodplain and terraces on the left side (Boengiu et al 2009).

A series of geodetic measurements about the vertical movements of the crust were carried out in the Rast - Lom sector between 1964 and 1986. The speed of the measured movements oscillated between - 12 mm / year and + 0.4 / year on the Calafat - Rast line (Rădulescu, 1996). On the interfluvium between Jiu and Olt, the map of the vertical crustal movements in 1985 showed positive movements of 1 mm / year (Popescu et al, 1987). We can conclude that in the Lom area the subsidence was more intense than the positive movements in this area, and if we add the rise of the interfluvium between the two large rivers in Oltenia, the Jiu river could have diverted to the west, of course if the movements had occurred for a long time.

Oscillations of the Jiu minor bed could have been caused by floods on the river. The flood from 1879 moved the course of the Jiu river with 15 km from east to west. At that moment the river was flowing into the Danube near Bechet and after the flood it changed it course (Savin 1990). Although we cannot always make a correlation between channel changes and floods due to lack of data, we can still note that after building a series of levees in the second half of the last century, the lateral oscillations of the stream bed have diminished. The years in which Jiu floods occurred, recorded by the hydrometric stations, were: 1940, 1953, 1972 at the Podari hydrometric station and 1969, 1972 and 1976 at Zăval (Savin. 1990). The maximum flood flow occurred in 1972 when the Podari station recorded 2000 m3 / s, a value that was recorded in the same year at Zăval. In 1953 at Podari station were recorded 1950 m3 / s, and in 1940 at the same station the maximum flow rate at flood was 1765 m3 / s (Savin, 1990).

From the cartographic analysis, we can see that over the last 50 years the Jiu course did not suffer any major lateral change. This situation can be explained, as suggested above, by raising levees. Thus, in 1962, the defense levee between Secui and Bratovoeşti (14,4 km, 1,7 m H) were put into operation, in 1972 between Rojişte and Murta (13,6 km, 1,5 m H), but also between Murta and Lişteava (15.8 km, 1.5 m H), in 1976 the levee that defended Lişteava (5.7 km, 3 m H) and in 1979 the levee between Podari and Ţuglui (14.5 km, 1.7 m H) was put into operation (PMRI, ABA Jiu, 2015). The levees prevented Jiu from spreading sideways through its floodplain, stabilizing the course.

Conclusion

Currently, the Jiu channel may seems stable, but, knowing its bedside oscillations over the historical time, we can consider it a very dynamic river. Maybe this river will continue to change its path as long as floods will take place, as long as its river banks are not consolidated and as long as slow or high tectonic movements are happening in this area.

The high roughness of the riverbanks, the building of the levees will moderate Jiu’s lateral migration and in the future we will try to write a paper about how rough are the Jiu river banks.

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References

Boengiu, S., Avram,. S., (2009), Bălăcița piedmont. A model of formation and evolution", Zeitschrift fur Geomorphologie - Annals of Geomorphology, Suppl. 2, Vol. 53, Stuttgart, 106 p., DOI: 10.1127/0372-8854/2009/0053S3-0101.

Boengiu, S., Vîlcea, Cristiana, Licurici, Mihaela, (2011a), Landslides in the Plain Sector of the Jiu Valley, Revista de Geomorfologie, nr. 13, ISSN 1453-5068, Editura Universității din București, p.75-81.

Callander, R.A. 1969: Instability and river channels. Journal of Fluid Mechanics 36, 365-480.

Coteț, P., (1957), Câmpia Olteniei – Studiu geomorfologic (cu privire asupra Cuaternarului), Editura Științifică, București.

Hooke, J.M., 2013. River meandering. In: Shroder, J. (Editor in Chief), Wohl, E. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 9, Fluvial Geomorphology, pp. 260–288.

Ionuș, Oana (2014) Preliminary data on the Jiu River meanders in the lower course (South-West Romania), Forum geografic. Studii și cercetări de geografie și protecția mediului, Volume XIII, Issue 1 (June 2014), pp. 18-24 (7), http://dx.doi.org/10.5775/fg.2067-4635.2014.026.i.

Leopold, L.B., Wolman (1957), River Channel Patterns - Braided, Meandering and Straight, United States Geological Survey, Professional Paper 282B.

Nicolescu, E. I., (1932) Contribuțiuni la hidrografia Olteniei – Bazinul Jiului, Scrisul Românesc S. A., Craiova.

Popescu, M., N., Drăgoescu, I., (1987) Maps of recent vertical crustal movements in Romania: Similarities and differences, Journal of Geodynamics 8(s 2–4):123–136.

Rădulescu, F., Mocanu, V., Nacu, V., Diaconescu Camelia, (1996), Study of recent crustal movements in Romania: A review, Elsevier Science Ltd., Journal of Geodynamics 22(1-2):33-50•September, Great Britain.

Rhoads, B.L., Welford, M.R., (1991), Initiation of river meandering. Progress inPhysical Geography 15(2), 127–156.

Savin C., (1990), Resursele în apă ale Luncii Jiului, Editura Scrisul Românesc, Craiova.

Planul de Management al Riscului la Inundaţii Administraţia Bazinală de Apă Jiu, accesat:http://www.rowater.ro/dajiu/EPRI/Planul%20de%20Management%20al%20riscului%20la%20Inundatii.aspx.

xxx Atlasul Cadastrului Apelor din România (1992).

https://www.openstreetmap.org/#map=11/44.0907/23.2131

http://www.charta1864.ro/charta.html

http://www.geo-spatial.org/download/harile-austriece-1910-reproiectate-in-stereo70

http://digitalarchive.mcmaster.ca/islandora/object/macrepo%3A9659.

http://www.geo-spatial.org.

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Considerations on the Influence of Micro Urban Heat Islands to the Temperature - Humidity Index During July 2017 in Craiova City Centre

Daniela ROȘCA[1], Adrian ROȘCA[2,*]

[1] University of Craiova, Faculty of Electrical Engineering, 107, Decebal Bld., 200404, Craiova, Romania
[2] University of Craiova Faculty of Horticulture, 13, Al. I. Cuza Street., 200585, Craiova, Romania
* *Corresponding author*, adrosca2003@yahoo.com

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Abstract

According to the National Administration of Meteorology, July 2017 was the hottest July months in the last decade, with one of the longest period with canicular temperatures in the last decades, too. In many regions of Romania, including Oltenia and Craiova city, too, yellow or orange code warning had to be announced. To determine real thermal discomfort sensation felt by the population of Craiova city, experimental research concerning micrometeorological measurements of the real temperature and relative humidity that contribute to the local Temperature - Humidity Index (THI) value was performed. According to the experimental research results, confirmed by using thermovision too, in Craiova city centre, five micro urban heat islands (MUHI) were identified. For three streets and a public square, despite the small mean value of relative humidity, due to the temperature's high mean value, in these hot spots the THI mean average was 89.97, and for this thermal discomfort sensation, special protection measures would be needed. The same air micrometeorological parameters in these four hot spots were compared with the ones recorded in English Park, where due to vegetation and trees' shadow, the THI average was 84.11, thus the real thermal discomfort sensation would have made necessary adequate protection measures. In order to study the intensity and spatial pattern of the MUHI, thermal infrared remote sensing (thermovision) was used to observe the surface of MUHI as a complementary indicator of the thermal discomfort sensation with in MUHI. The paper presents relevant interdependence relationships between the near surface air temperatures and pavement/ buildings surface temperatures that have been found for MUHI in Craiova's city centre. The paper proposes practical methods that could be used to decrease the pavements' and buildings' walls temperatures, thus contributing to the decrease of THI in the MUHI within Craiova city centre.

Keywords: *micro urban heat islands, hot spots, temperature - humidity index, thermovision*

Rezumat. Consideraţii privind influenţa insulelor de cădură urbane asupra indicelui temperatură - umiditate în luna Iulie 2017 în centrul oraşului Craiova

Conform Administraţiei Naţionale de Meteorologie, luna iulie a anului 2017 a fost cea mai fierbinte lună iulie din ultimul deceniu, cu una dintre cele mai lungi perioade cu temperaturi caniculare din ultimile decade. In Oltenia, precum şi în oraşul Craiova, a trebuit să fie anunţate avertizări de cod galben sau portocaliu. In vederea evidenţierii stării reale de disconfort termic resimţită de populaţia din Craiova, au fost efectuate cercetări experimentale privind măsurători micrometeorologice pentru determinarea temperaturii şi umidităţii reale care contribuie la stabilirea indicelui de confort termic local. În conformitate cu rezultatele cercetărilor experimentale, confirmate şi prin utilizarea termoviziunii, în centrul Craiovei au fost identificate cinci microinsule de căldură local urbane (MUHI). Pentru trei străzi şi o piaţă publică, chiar şi pentru valori reduse ale umidităţii, datorită temperaturilor mari, în aceste zone fierbinţi media indicelui de confort termic a fost 94,93, şi senzaţia de disconfot termic ar fi făcut necesare măsuri speciale de protecţie. Parametrii micrometeorologici determinaţi în aceste patru zone fierbinţi au fost comparaţi cu cei obţinuti în English Park, unde datorită prezenţei vegetaţiei şi a umbrei arborilor, valoarea medie a indicelui de confort termic a fost de 84,87, deci senzaţia de disconfort termic af fi necesitat măsuri de protecţie adecvate. În vederea studiului intensităţii şi distribuţiei spaţiale în MUHI, pentru măsurarea temperaturii suprafeţelor din MUHI fost utilizată termoviziunea, ca metodă complementară de evaluare a disconfortului termic. Lucrarea prezintă relaţii de interdependenţă dintre temperatura aerului deasupra pavimentului, şi temperatura pavimentului şi a pereţilor clădirilor în MUHI din centrul Craiovei. Lucrarea prezintă câteva metode practice care ar putea fi utilizate pentru reducerea temperaturii pavimentului şi a pereţilor clădirilor, care ar contribui la scăderea indicelui de confort termic din MUHI din oraşul Craiova.

Cuvinte-cheie: *insulele de căldură local urbane , zone fierbinţi, indice temperatură – umiditate, termoviziune*

Introduction

Heat wave in Oltenia and in Craiova city

Craiova City, as one of the largest city of the country, with a population of some 300.000, has a built - up gentle relief plain area of approximately 32 km^2, from 92 to 117 m a.s.l., with 9.0 – 9.4 km maximum extension in N – S direction, and 4.8 – 5.2 km minimum extension in E - W direction. Due to continental – temperate climate, during the warm season, but especially in the June – August period, in the last century, Craiova registered the highlest mean monthly temperature (28.5^{o}C) in July, and maximum absolute monthly temperature peaking at 41.5^{o}C (July 1916), respectively (Cocean, 2011; Boengiu, 2008). The term *canicular* characterizes weather condition in which air temperature, measured in standard conditions at meteorological stations reaches or even exceeds the threshold of 35°C on extended areas. During the last 20 years, the drought period in Oltenia Region started in January 2000 lasting until July, 17th 2002, so during the summer of 2000, there was canicular weather for extended periods of time. The drought of 2000 was in general extremely intense and associated with extended periods of canicular weather and heat waves in the intervals: June 6-10, 21-25, July 2-12, 22-27, August 3-7, 17-24. It affected the entire social life, causing the increase of all life prices (Marinică and Marinică, 2014). In the summer of 2007, in Oltenia, weather was extremely changeable. Among the most important weather aspects, there must be mentioned six heat waves in the intervals (June 19-26; July 2-4; 8-10; 15-24; 27-30; August 22-25), two of these had a great intensity (the ones in the interval June 19-26 and in the interval 15-24 July, respectively). The heat wave from July 15^{th} to24^{th}, 2007 was the most intense for this month for the entire period since meteorological observations are carried out and marked the exceeding of the monthly absolute maximum thermal value of July with 0.8°C: 44.3°C registered at Calafat on July 24^{th}, which in that period was the absolute maximum thermal value of July in Romania; the old absolute maximum thermal value of July in Romania was 43.5°C registered at Giurgiu on July 5, 2000 (Marinică and Chimişliu, 2009; Marinică and Marinică, 2014). It must be noticed that in July 2007, for the first time, the air temperature reached and exceeded the climatologically threshold of 44°C. In July 2007, values higher or equal to 44°C were also registered at three meteorological stations in Oltenia: Băileşti 44.0°C, Bechet 44.2°C and Calafat 44.3°C, which means a more extended area of hot air than in the last century. At soil surface, the maximum thermal value registered in Calafat was 69.0°C, and in Băileşti 71.0°C, the diurnal thermal amplitude being of about 45°C (Marinică and Marinică, 2014). In Oltenia Region, September 2012 was excessively warm, when for 14 days, the maximum temperature values were comprised between 30° and 35°C (Marinică and Marinică, 2013).

According to the National Administration of Meteorology (NAM), in the period 2015 – 2017, July months were canicular in Craiova, when the maximum temperatures reaching 36.7°C (July 30, 2015), 34.2°C (July 14, 2016) and 38.4°C (July 1, 2017) (http://www.accu-weather.com/en/ro/craiova/287856/july-weather/287856).

Urban Heat Island

An Urban Heat Island (UHI) describes the characteristic warmth of both the atmosphere and surfaces in urban areas compared to their non-urbanized surroundings. There are three different types of heat islands: Canopy Layer Heat Island (CLHI), Boundary Layer Heat Island (BLHI), Surface Heat Island (SHI). The first two refer to the urban atmosphere warming; the last one refers to the relative warmth of urban surfaces. The urban canopy layer is the layer of air closest to the surface in cities, extending upwards to approximately the mean building height. Heat island types vary in their spatial shape, temporal characteristics, and some of the underlying physical processes that contribute to their development. Meteorologists measure air temperatures for CLHI or BLHI directly using thermometers, whereas the SHI is measured by remote sensors mounted on satellites (as LST method) or aircraft (Voogt, 2002; Voogt, 2004).

Over the last decades, remotely sensed thermal infrared data have contributed to address the UHI through the estimation of land surface temperature, thus originating the study of the surface UHI. Nevertheless, it has been found that atmospheric and surface UHI are coarsely related, and they can exhibit quite different spatial and temporal patterns. Moreover, within the urban atmosphere the heat island may present significant variations between the canopy and boundary layer (www.urbanheatislands.com).

The progressive replacement of natural surfaces (often composed of vegetation and moisture soils) by built surfaces constitutes the main cause of UHI formation (www.urbanheatislands.com).

Therefore, characteristics such as development, growth, intensity, and spatial pattern of the UHI will differ depending on where the measurements are made. The atmospheric UHI usually reaches its highest intensity in summer, under calm air and a cloud-less sky (Sham et. al., 2012).

In order to study the intensity and spatial pattern of the UHI, in the last two decades, world-wide thermal infrared remote sensing was used to observe the surface of urban heat island as a reliable indicator of the atmospheric urban heat island. Therefore, close relationships between the near surface air temperatures and land surface temperatures have been found (Lo, Quattrochi and Luvall, 1997; Pérez Arrau, 2007; Roşca and Roşca, 2015; Voogt and Oke, 2003; Weng, 2009; Nichol, 2009; www.urbanheatislands.com).

Micro urban heat islands (MUHI) refer to urban hot spots as poorly vegetated, parking lots, non-reflective buildings materials, material and color of pavement and asphalt roads. MUHI are strongly affected by micro climate factors, therefore remotely sensed data (as thermovision) are more suitable than atmospheric data for identifying heat spots (Roşca and Roşca, 2015; Synnefa et al., 2006, 2007, 2009; Stathopoulou et. al., 2005, 2009; www.urbanheatislands.com).

As consequence of canicular heat wave on MUHI, the *Temperature-Humidity Index* (THI) has to be considered. THI, also known as *thermal comfort index*, represents the most used index in world-wide mass-media nowadays; it renders an apparent temperature, namely the temperature felt by human body that cools slower at higher values of the relative humidity due to the reduction of the evaporation rate. THI is calculated with the formula which corroborates air temperature and relative humidity, the critical threshold being 80. If THI is smaller than 65, it means comfort state; 66-79 means alert state; higher than 80 means discomfort state (Teodoreanu and Bunescu, 2007).

In the last decade, the Romanian researchers focused their interest for THI effects in Oltenia region. According to statistical data supplied by Craiova Regional Meteorological Center (CRMC), it was observed that 2000, 2001 and 2007 were the years with the highest number of days (51 days in 2000, 47 days in 2001, and 41 days in 2007) with THI values above 80 for the entire Oltenia territory, when, during July and August, the region was affected by numerous heat waves temperatures frequently exceeding 40°C (Burada and Sandu, 2009; Marinică and Marinică, 2008, 2009).

According to NAM, high THI values of 75 – 80 were recorded in 2015 and 2016 in Craiova, too.

According to the weather forecast provided to the media by the NAM, for large regions of Romania, in July 2017 canicular heat wave was settled, with many daily maximum thermal values reaching 35°C. Therefore in all these regions, and in Oltenia and Craiova, too, yellow or orange code warning had to be announced (http://www.accuweather.com/en/ro/craiova/287856/july-weather /287856).

Aims

Few years ago, Craiova benefited of financing funds provided by a European Project, aiming at the rehabilitation of the old down town; thus some streets became pedestrian areas, surrounded by small shops, pubs and restaurants. Rehabilitation took into account the structure and the facade of buildings, pavement and all the infrastructure (electricity, water, sewerage). Buildings' facades of more than 100 years old buildings; about 60 years old ground floor and 4 floor blocks have been rehabilitated (light colours, architectural ornaments), and the old pavement was replaced by a new one made in synthetic granite cubes (gray, dark gray, dark red) and artificial marble tiles (beige, dark white) (Roşca and Roşca, 2015).

For only ten days of July 2015, a previous study presented an overview concerning the influence of micro urban heat islands to the THI. This study was focused on identifying the hot spots that determine MUHI points in three streets, a large public square and in a public park in Craiova's city centre (Roşca and Roşca, 2015).

The present paper presents a similar overview for all the days of July 2017 (excepting colder and rainy days of the 3rd and 16th of July), in the same hot spots studied in 2015.

Thus, the present paper considers Craiova MUHI for five places: three rehabilitated streets (Panait Moşoiu, Lipscani, Theodor Amann Streets), Prefecture Square and English Park, respectively.

The experimental research considered the direction and the geometry of these five places: Panait Moşoiu Street - N – S direction, about 120m long, 15m wide, mean height of the buildings 12m, with no vegetation; Lipscani Street - E – W direction, about 330m long, 12m wide, mean height of the buildings 10m, with no vegetation; Theodor Amann Street - N – S direction, 130m long, 22m wide, mean height of the buildings 18m, with very poor vegetation; Prefecture Square (but without the Unirea Street that starts in the southern part of this Square) - open space 60 x 80m, with the Prefecture Building (30m high) to the East, an open green park with artesian fountains to the West, shops and 4 floors blocks (25m height) to the South, shops and 4 floors blocks (20m height) to the N, with no vegetation; English Park - open public green park 60 x 60m, with the Prefecture Building (30m height) to the West, Theodor Amann Street (shops and 4 floors blocks, 22m height) to the East, shops and 4 floors blocks (15m height) to the South; Craiova City Hall (15m height) to the North (Roşca and Roşca, 2015).

Craiova city is located in the S-W of Romania, with the city centre situated at the intersection between the parallel 44°19'01.70" N lat., with the meridian 23°47'50.99" E long. The NAM's meteorological data are provided by the CRMC's meteorological station (44°18'37.90" N lat.; 23°52'03.32" E long.) placed near the Airport of Craiova. Thus, the linear distance between CRMC's meteorological point and Craiova city centre (English Park) is 12 km.

The aim of this paper is to determine the temperature felt by human body at higher values of the air temperature and the relative humidity, and finally the real THI in the five hot spots that determine MUHI in Craiova city centre.

Material and methods

The micrometeorological measurement method presented in this paper intends to determine the real THI in each MUHI identified in the centre of Craiova city. The daily micro-meteorological experimental measurements carried on for 29 days in July 2017 were represented by five observations (from 60 to 60 min) in the hourly interval 13 – 17 (when maximum temperature was registered), for each MUHI in the five places mentioned above. The air temperature and air relative humidity, streets' pavement temperatures and park's grass and trees canopy temperatures too, were recorded in the middle of each rehabilitated street, in the center of the

Prefecture Square, and two different places in English Park.

Experimental research was focused to measure the real air maximum temperature and air relative humidity in the three streets and Prefecture Square (T_{MAS} and H_{MAS}), and in the park (T_{MAP} and H_{MAP}), respectively. Air temperature and air relative humidity were measured with hygrometer (Lutron HT - 3009: humidity accuracy ± 2% R.H; temperature accuracy 0.5^{0}C). In all the 29 days when the air temperature and air relative humidity measurements were realised, the air velocity was 1...2 m/s (hot wire anemometer (Lutron YK - 2005AK: air velocity accuracy ± 1% full scale; temperature accuracy ± 0.8^{0}C; measured at 1.2...1.4 m height above the ground) and the nebulosity was 0...50%.

Experimental research was focused also on measuring using a thermometer (contact method) the maximum temperatures of the streets pavement (T_{MPS}) and the maximum temperatures of the grass and trees canopy in the park (T_{MGP}), and the streets' buildings and pavement temperatures ($T_{IR.PS}$) and the park's grass and trees canopy temperatures ($T_{IR.GP}$) too, by using thermal infrared camera (thermovision - non contact method).

For each temperature measurement a precision fine wire thermo-couples (Omega 5 SC-GG-K-30-36; accuracy ± 0.5%), and a temperature data - logger recorder (Lutron BTM - 4208 SD) were used.

All the data presented in Table 1 represent the average of the maximum values determined in the five observations / measurements in the three streets, Prefecture Square and English Park. The real maximum air temperature and air relative humidity measured during the experimental research, were compared with the air maximum temperature (T_{NAM}) and air relative humidity (H_{NAM}) provided by NAM (http:// www.accuweather.com/en/ro/craiova/287856/july).

Based on these measured data, the THI was calculated using the formula provided by Teodoreanu and Bunescu, 2007:

$$THI = (1.8 \cdot T + 32) – (0.55 – 0.0055 \cdot H) \cdot [(1.8 \cdot T + 32) – 58)],$$

where T - air temperature (°C), H - air relative humidity (%). According to this relation there were obtained THI_{NAM}= f (T_{NAM}, H_{NAM}); THI_{MAS}= f (T_{MAS}, H_{MAS}); THI_{MAP} = f (T_{MAP}, H_{MAP}), where T_{MAS} represents the average of air maximum temperatures measured on the streets and Prefecture Square and T_{MAP} represents the average of air maximum temperatures measured in English Park, respectively.

Thermal infrared sensing camera FLIR T 200 was used (FPA uncooled microbolometer detector type; 7.5 - 13 µm spectral range; resolution 324 x 256 pixels; NETD < 0.045^{o}C). For each thermal infrared measure-ment, on the thermal infrared camera, 5 parameter (Emissivity, Distance, Refl. temp., Rel. humidity, Atm. Temp.) were necessary to be set. For air relative humidity (Rel. humidity) and air temperature (Atm. temp.) there were used the values measured with the hygrometer (Lutron HT – 3009).

The reflected temperature (Refl. temp.) was determined with aluminium foil, for emissivity ε = 1, distance d = 0 m.

In a thermal image, each material of the buildings' facades and the streets' pavement materials is characterised by certain specific emissivity.

According to the professional emissivity tables, both for buildings' facades and for pavement materials, the mean emissivity ε = 0.92 was selected. According to the same professional tables, the emissivity for grass ε = 0.97, for leaves ε = 0.98, for bark ε = 0.94; therefore, for the vegetal's emissivity, the mean of those mentioned materials, ε = 0.96, was used (www.icess.ucsb.edu/modis/; www.zytemp.com/infrared/application.asp).

In order to verify the thermal infrared temperature correctness in the streets ($T_{IR.PS}$) and in English Park ($T_{IR.GP}$) too, two precision fine wire thermo-couples (Omega 5 SC-GG-K-30-36), and a temperature data - logger recorder (Lutron BTM - 4208 SD) were used: streets - one on the pavement, placed at 1 m from the building wall and one on the building wall at 1 m height from the ground; park - for vegetal material, one on the grass / ground, placed at 1m from the tree trunk, one in the canopy of the tree's crown, respectively. Each thermal infrared measure was considered correct only when the difference between the temperature in the spot of the thermal image, and the measured temperature of the pavement / building (contact method), was less than 2^{o}C.

Results and discussions

Table 1 presents the daily data provided by NAM (T_{NAM} and H_{NAM}), the data obtained during the experimental measurements (T_{MAS} and H_{MAS}; T_{MAP} and H_{MAP}; T_{MPS}; T_{MGP}; $T_{IR.PS}$; $T_{IR.GP}$), the calculated THI (THI_{NAM}; THI_{MAS}; THI_{MAP}) and the monthly average for all those data, too for each MUHI. According to NAM, out of the 29 analysed days of July 2017, there were recoded: 15 days with low / normal temperatures 26.1 - 31.9^{o}C; 14 days with high temperatures 32.1 - 38.4^{o}C.

There were four intervals with successive days when the temperature exceeded 32^{o}C: 1 - 2 July (38.4 - 32.4^{o}C); 9 - 13 July (32.3 - 35.6^{o}C); 21 - 24 July (32.8 - 36.7^{o}C); 29 - 31 July (32.1 - 33.7^{o}C); four canicular days 1, 11, 22, 23 July (38.4°C, 35.6°C, 35.7°C, 35.3°C).

Table 1: Comparison between the experimentally measured data and the data announced by National Administration of Meteorology

DAY	NAM VALUES		MEASURED PARAMETERS VALUES						INFRARED VALUES		THI_{NAM}	THI_{MAS}	THI_{MAP}
	T_{NAM}	H_{NAM}	T_{MAS}	T_{MAP}	T_{MPS}	T_{MGP}	H_{MAS}	H_{MAP}	$T_{IR.PS}$	$T_{IR.GP}$			
1	38.4	20	46.8	41.9	51.7	45.2	37.2	41.7	53.4	46.7	82.1	96.1	91.6
2	32.4	35	41.5	35.4	45.9	38.3	43.1	47.8	46.5	39.9	78.8	91.4	84.9
4	26.5	45	32.1	28.2	34.4	31.1	50.3	55.5	35.7	32.5	73.1	81.19	76.8
5	29.7	29	39.1	32.9	42.1	36.3	45.5	52.5	43.5	37.6	74.7	89	82.5
6	30.9	30	40.2	34.1	44.4	37.7	45.2	49.5	46.1	39.4	76.2	90.3	83.6
7	29.4	38	38.9	33.4	42.2	36.2	45.6	52.5	43.1	37.1	75.7	88.8	83.2
8	31.9	33	41.8	35	45.5	38.2	44.1	48.6	47.2	40.1	77.8	92.1	84.5
9	33.8	29	42.9	36.2	46.8	39.8	41.3	46.2	48.1	41.5	79.2	92.6	85.6
10	33	36	41.9	36.1	45.6	39.4	41.8	46.9	47.2	41.4	79.6	91.6	85.6
11	35.6	33	44.5	38.9	49.7	42.6	42.6	47.3	51.5	44.3	82.0	95	89.3
12	32.4	39	41.1	35.3	45.7	38.5	43.5	48.1	47.3	40.2	79.5	91	84.8
13	32.3	33	40.8	35.3	45.3	38.1	43.1	48.4	47.1	39.8	78.3	90.5	84.9
14	27.3	39	35.1	31.2	37.1	34.3	48.3	54.3	38.2	35.5	73.4	84.6	80.6
15	27.7	42	35.3	31.7	37.4	34.5	47.9	53.4	38.6	35.9	74.2	84.7	81.1
17	26.1	42	31.3	27.1	33.4	28.9	50.1	55.9	34.8	30.1	72.3	80.1	75.3
18	29.4	35	38.5	33.6	41.9	36.4	45.8	52.2	42.8	37.6	75.3	88.3	83.4
19	31.3	32	40.5	34.8	44.9	38.1	44.4	49.7	46.7	39.9	77.0	90.5	84.5
20	30.9	31	40.2	34.4	44.5	37.9	45.7	51.1	46.6	39.4	76.4	90.5	84.3
21	32.8	30	41.7	35.7	45.4	38.6	42.9	47.2	47.1	40.3	78.3	91.6	85.1
22	36.7	24	45.3	39.6	50.8	43.7	39.4	43.7	52.3	45.2	81.3	95	89.3
23	35.3	29	44.2	38.4	49.3	42.1	43.5	47.6	50.9	44.1	80.9	94.9	88.7
24	34.3	34	43.5	36.8	47.4	40.6	40.9	45.3	48.9	42.2	80.8	93.2	86.1
25	29.9	34	39.4	33.2	42.6	36.9	46.3	52.4	43.9	37.8	75.7	89.6	82.9
26	26.5	39	34.4	30.6	36.5	33.6	49.7	55.2	37.9	34.7	72.4	83.9	79.9
27	29.5	26	38.8	33.1	42.2	36.3	45.8	52.9	43.2	37.4	74.1	88.7	82.9
28	30	32	39.3	32.7	43.2	35.1	47.3	51.9	44.8	37.2	75.5	89.7	82.2
29	32.1	24	40.9	34.9	45.3	38.3	43.2	47.8	46.8	40.1	76.5	90.7	84.2
30	32.7	23	41.2	35.8	45.5	38.7	43.8	48.2	47.1	40.6	76.9	91.2	85.5
31	33.7	26	42.5	36.5	46.2	39.8	42.4	47.1	48.2	41.4	78.6	92.5	86.1
AVG	**31.46**	**32.48**	**40.12**	**34.57**	**43.89**	**37.76**	**44.50**	**49.68**	**45.36**	**39.30**	**77.13**	**89.97**	**84.11**

Craiova's MUHI took into consideration hot spots as very poor vegetated three walking streets and Prefecture Square, determined by non-reflective and high thermal inertia of buildings materials, colour and material of the pavement.

It must be mentioned the important role of the streets and buildings cover types have on the thermal pattern (air temperature and relative humidity values) of each MUHI, and the relationship between the temperature radiated by the streets (and the atmosphere temperature situated immediately above it), and buildings' facades surfaces too, due to the transfer of energy emitted from the former to the latter.

Due to high temperatures of the streets' pavement T_{MPS} = 43.89°C, and of the park's vegetation T_{MGP} = 37.76°C too, the mentions above are confirmed for each MUHI in all the five places (streets, public large square, public park) where the measured air temperature and relative humidity values are significantly higher than the NAM data:

$T_{MAS} - T_{NAM}$ = 8.66°C; $H_{MAS} - H_{NAM}$ = 13.04°C;

$T_{MAP} - T_{NAM}$ = 3.11°C; $H_{MAP} - H_{NAM}$ = 17.2°C.

Consequently, even THI_{NAM} = 77.13 (alert state), the real thermal comfort on the streets and in Prefecture Square THI_{MAS} was 12.84 grater (discomfort state), and even in English Park THI_{MAP} was 6.98 grater (discomfort state), too.

The values for July 2017 presented in Table 1, in the five specific MUFI identified in the Craiova city centre, confirm the general information presented in the literature concerning the influence of micro urban heat islands to the temperature - humidity index (Sham et. al., 2012). Because construction materials exhibit a high thermal inertia (a low response to temperature changes, and consequently, they continue releasing heat slowly after sunset. Meanwhile, light winds are not capable to produce turbulent exchanges of heat, while clear skies enhance rural cooling by allowing radiative heat loss to the relatively cold night sky. The MUHI measured parameters may exhibit high spatial and temporal variation.

Since urban temperature is strongly commanded by the high thermal inertia of the construction materials, the surface MUHI usually reaches its highest intensity in the afternoon, when the urban surface has sufficiently warmed-up, thus maximizing its heat release.

The above considerations are emphasized by thermal infrared remote sensing that was used to observe the urban heat island surface, as a reliable indicator of the atmospheric parameters of each MUHI.

According to Table 1, the difference between the maximum temperatures of the streets' pavement and buildings determined using a contact method / infrared camera ($T_{IR.PS}$) and the maximum temperatures of the streets' pavement measured using contact method / wire thermo - couple (T_{MPS}) is only 1.49°C; similarly, the difference between the maximum temperatures of the grass and trees canopy in the park determined with non-contact method / infrared camera ($T_{IR.GP}$) and the one measured using contact method / wire thermo - couple (T_{MGP}) is only 1.54°C.

Due to thermal infrared remote sensing accuracy, an important relationship between the near surface air measured temperatures and land surface temperatures have been found:

$T_{IR.PS}$ - T_{MAS} = 5.24°C; $T_{IR.GP}$ - T_{MAP} = 4.73°C;

$T_{IR.PS}$ - T_{NAM} = 13.9°C.

Built surfaces (buildings' facades; pavement) are composed of a high percentage of non-reflective and water-resistant construction materials. Consequently, they tend to absorb a significant proportion of the incident radiation, which is released as heat. As a result, the variable thermal properties of the urban construction materials, in combination with the three dimensional geometry of built-up surfaces, modify neighbouring air temperatures.

The narrow arrangement of buildings along the city's streets forms *urban canyons* that inhibit the escape of the reflected radiation from most of the three-dimensional urban surface to space.

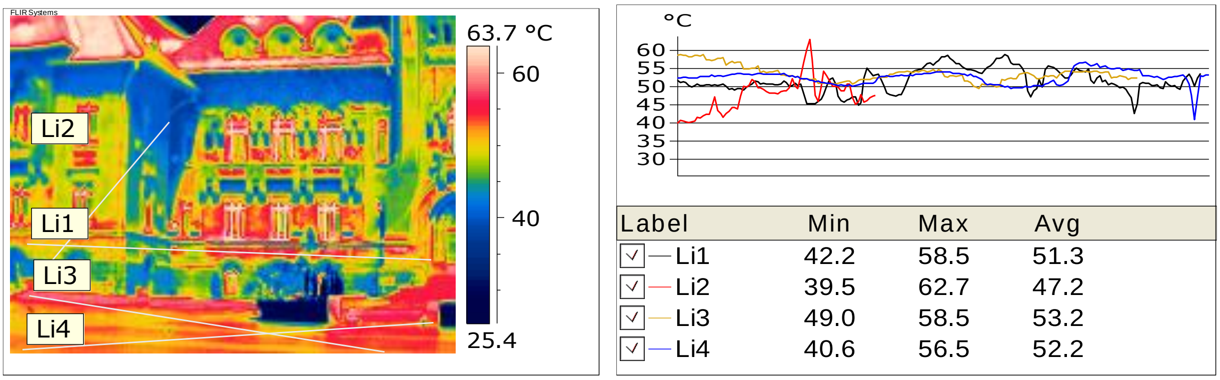
This radiation is ultimately absorbed by the building walls, thus enhancing the urban heat release. Moreover, light winds are not capable to produce turbulent exchanges of heat leading to radiative heat losses.

For each MUHI, representative thermal images and temperature graphics in certain hot spots are presented in figures 1-5.

Consequently, within Prefecture Square (open space with a green park to the West; white, light yellow and light orange colours for the buildings' facades; beige color of the synthetic granite tiles) a hot spot was observed. Prefecture Square is the main public square of the city, used especially for social, political and cultural activities. Therefore when it was designed, no high vegetation was possible.

In thermal image and temperature graphics presented in figure 1, it is observed that even if the buildings' facades and pavement's, too, are light coloured, the maximum temperatures of those surfaces were 58.5...62.7°C (Li1 and Li2).

The temperatures on the pavement (light gray color synthetic granite) near the fountain's water sprinkle was 56.5...58.5°C (Li 3 and Li4).



Label	Min	Max	Avg
Li1	42.2	58.5	51.3
Li2	39.5	62.7	47.2
Li3	49.0	58.5	53.2
Li4	40.6	56.5	52.2

Fig. 1: Thermal images and temperature graphics recorded in Prefecture Square

Thermovision emphasized the same canyon effect for Lipscani Street (no tree; white, light yellow and light orange colours for the buildings' facades; dark white colour for artificial marble tiles of the pavement), too. The thermal image and temperature graphics presented in figure 2 indicates that even if the buildings' facades and pavement's, too, are light coloured, the temperatures of those surfaces were 47.4...48.6°C (Li1 and Li2) and 51.4...55.3 (Li3 and Li 4), respectively.

The same canyon effect was identified for Theodor Amann Street as well (very low vegetated; white, light yellow and light orange colours for the buildings' facades; dark white colour for artificial marble tiles and gray granite cubes of the pavement).

Thermal image and temperature graphics presented in figure 3 point that even if the buildings' facades and pavement's, too, are light coloured, the maximum temperatures of those surfaces were 43.4...44.1°C (Li1 and Li2) and 50.6...53.9°C (Li3 and Li4), respectively.

Figure 4 depicts representative thermal images and temperature graphics recorded for Panait Moşoiu Street where canyon effect was observed, too (no trees; white, light yellow and light orange colors for the buildings' facades; dark gray and dark red colours for synthetic granite cubes of the

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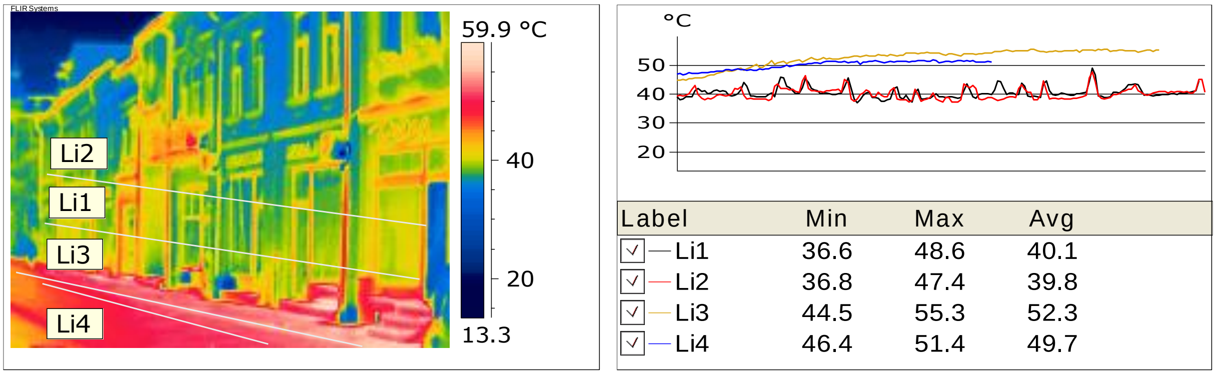
pavement). Even if the buildings' facades are in light colors, the maximum temperature of those surfaces was 45ºC (Li1 and Li2). Due to the dark color pavement, the maximum temperature of this surface was 54.1... 54.9ºC (Li3 and Li4).

Natural surfaces utilize a relatively large proportion of the absorbed radiation in the evapo-transpiration process and release water vapours, thus cooling the air in their vicinity.

In contrast, built surfaces are composed of non-reflective and water-resistant construction materials and consequently, they tend to absorb a significant proportion of the incident radiation, which is released as heat, and very large values for THI occurred.



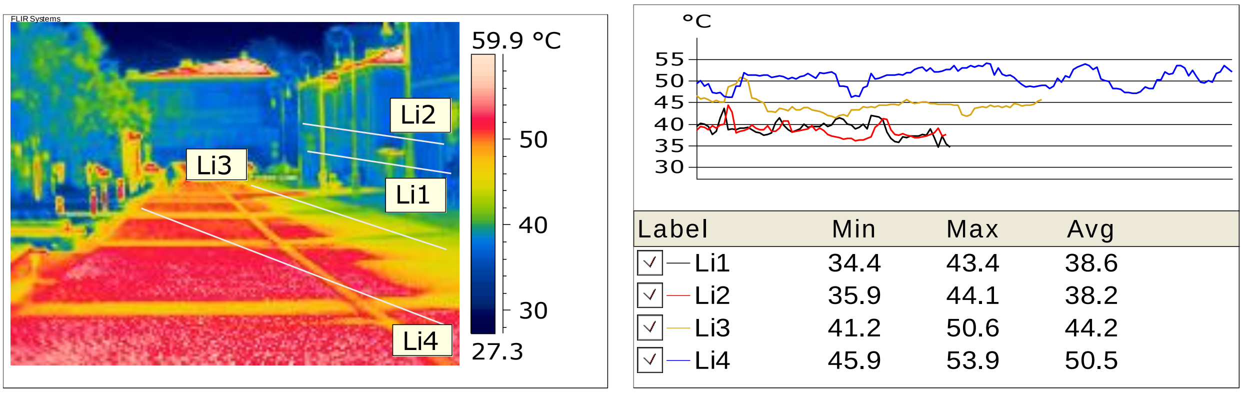
Label	Min	Max	Avg
Li1	36.6	48.6	40.1
Li2	36.8	47.4	39.8
Li3	44.5	55.3	52.3
Li4	46.4	51.4	49.7

Fig. 2: Thermal images and temperature graphics recorded along Lipscani Street

Vegetation intercepts radiation and produces shade that also reduces urban heat release. The decrease of parks and vegetated areas, not only reduces these benefits, but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and hot spots urban areas.

In comparison with the above presented hot spots, figure 5 presents a representative thermal image and temperature graphics for English Park.

On the trees' crowns (sunny and shady zones) maximum / average temperature was 39.7…40.3ºC / 36.6...37.1ºC (Li1 and Li2), and the grass / ground (sunny and shady zones) maximum / average temperature was 38.8…45.5 ºC / 32.8...38.4 ºC (Li3 and Li4).



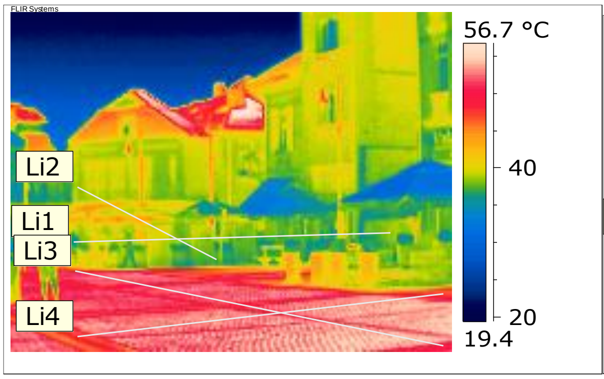
Label	Min	Max	Avg
Li1	34.4	43.4	38.6
Li2	35.9	44.1	38.2
Li3	41.2	50.6	44.2
Li4	45.9	53.9	50.5

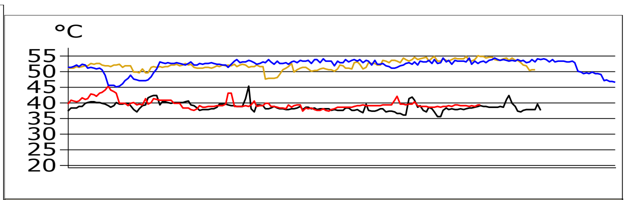
Fig. 3: Thermal images and temperature graphics recorded along Theodor Amman Street

Urbanism architects who contributed to this rehabilitation design should have taken into account that in the past 15 years, the summer months in Craiova have become increasingly warmer.

It should be mentioned here for the analysed area covers 9000 m^2 (3 streets and Prefecture Square), there are less than 30 trees. This very poor vegetated area in the hot spots contributes to a large extent to the high temperatures and thermal discomfort sensation that people must deal with.

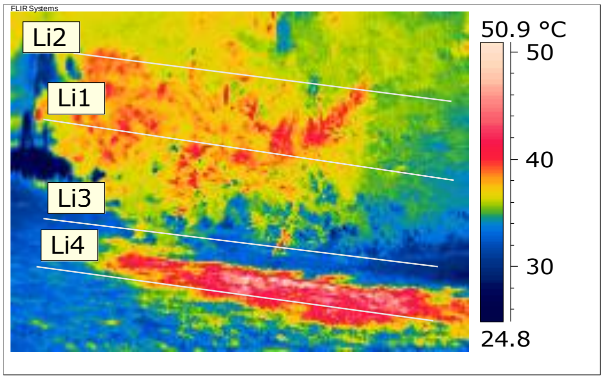
To reduce the hot spots effects into the micro urban heat islands in Craiova's city centre, a strategically method should be recommended: vegetation increasing that in the same time, will contribute to decrease the urban pollution levels.

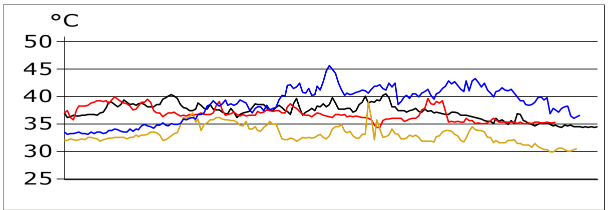




Label	Min	Max	Avg
Li1	35.3	45.0	38.4
Li2	37.0	45.0	39.3
Li3	47.4	54.9	51.9
Li4	44.9	54.1	51.8

Fig. 4: Thermal images and temperature graphics recorded along Panait Moşoiu Street





Label	Min	Max	Avg
Li1	34.1	40.3	37.1
Li2	34.2	39.7	36.6
Li3	29.7	38.8	32.8
Li4	32.9	45.5	38.4

Fig. 5: Thermal images and temperature graphics recorded in English Park

To a large extent, the rehabilitation of the streets analyzed in this paper considered the use of the light colours for built surfaces (buildings' facades; pavements). Unfortunately, due to their non-reflective characteristics, all construction materials that have been used for this rehabilitation absorb the incident radiation, that is subsequently released as heat.

In order to decrease the pavements' temperature in the hot spots both in the Prefecture Square and on the rehabilitated streets, an operative, efficient and low cost method should be used: a water sprinkling small car, or temporary water sprinkling system similar with water-fog devices.

Fig. 6: Digital model of modular temporary shady cover for Panait Moşoiu Street

Fig. 7: Digital model of modular temporary shady cover for Theodor Amann Street

In all the hot spots, a simple method that could reduce the reflected radiations' escape from the buildings' walls to neighborhoods consists in permanent or temporary retractable roofs /covers that provide shady zones.

Figure 6 and figure 7 present digital models of modular temporary shady covers proposed for Panait Moşoiu and Theodor Amann Streets.

Conclusions

According to the National Administration of Meteorology (NAM), the month of July 2017 was the hottest July month during the last decade, with one of the longest period with canicular temperatures in the last decades, too. Therefore, in Oltenia and in Craiova city, too, there was a yellow or orange code warning.

In order to determine the real thermal discomfort sensation felt by the population of Craiova, experimental research concerning micrometeorological measurements of real temperature and relative humidity those contribute to the local Temperature – Humidity Index was performed.

According to the experimental research results, confirmed by using thermovision too, four hot spots (three rehabilitated streets and Prefecture Square) were identified in Craiova's city centre.

Despite the low mean value of relative humidity (44.5%), due to the temperature high mean value (40.12^{0}C), in these hot spots the THI average was 89.97, and the thermal discomfort sensation occurred, thus special protection measures were necessary.

The same micrometeorological air parameters in the hot spots were compared with the ones recorded in English Park where due to trees' shadow, temperature and relative humidity averages were 34.57^{0}C, and 49.68%, respectively. Even if the mean temperature was 5.55^{0}C lower and relative humidity 5.18% higher than in the hot spots, the THI average was 84.11 (5.86 lower than in the hot spots), the thermal discomfort sensation occurred, thus special protection measures were necessary.

In order to study the intensity and spatial pattern of the UHI, thermal infrared remote sensing was used to observe the surface of urban heat island as a reliable indicator of the atmospheric microurban heat island. Therefore, close relationships between the near surface air temperatures and land surface temperatures have been found for microurban heat islands in Craiova's city centre.

The experimental results confirm that due to the variable thermal properties of the construction materials (building, pavements) combined with the three - dimensional geometry of built-up surfaces, the neighboring air temperatures increase. In the same time, the narrow arrangement of buildings along the streets leads to urban canyons phenomenon, that inhibit to space the reflected radiation's escape from the three - dimensional buildings' shape and pavements' surfaces. This radiation is absorbed by the building walls and the pavement, thus enhancing heat's release from the micro urban hot spots. On other hand, very light winds are not capable to obtain heat's turbulent exchanges.

Vegetal surfaces utilize a relatively large proportion of the absorbed radiation in the evapo-transpiration process and release water vapours that cool the air.

Vegetation intercepts radiation and produces shade that also contributes to heat's release reducing. The decrease of parks vegetated areas, not only reduces these benefits, but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and micro urban' areas hot spots.

In contrast, built surfaces are composed of non-reflective and water-resistant construction materials, and as consequence, they absorb a significant proportion of the incident radiation, which is released as heat, and very large values for THI occurred.

According to these considerations, in order to decrease the pavements temperatures in the hot spots, an operative, efficient and low cost method consisting in modular temporary shady cover could be used. A cheaper and shorter term method would be to use permanent or temporary vertical walls and modular roofs made by ornamental green vegetation.

In order to increase the vegetated area in the micro urban hot spots, that will also decrease pollution, in the near future concerted efforts of a consortium of urbanism architects, meteorologists, ornamental plants and trees specialists and environment urban pollution engineers are needed.

References

Boengiu, S. (2008). Bălăciţa Piedmont. Geographical Study, Universitaria Craiova Publishing House, ISBN 978-606-510-321-4.

Burada, C., Sandu, O. (2009). The July 2007 Heat Wave in Oltenia (South-West of Romania) in the Context of Climate Change, Geographia Technica, no.1, Cluj Napoca.

Cocean, P. (coord.). (2011). Urban development strategies. Case study - Craiova, Presa Universitara Clujeana Publishing House, ISBN 978-973-595-257-0.

Lo, C.P., Quattrochi, D.A., Luvall, J.C. (1997). Application of high - resolution thermal infrared remote sensing and GIS to assess the urban heat island effect. International Journal of Remote Sensing, 18(2): pp. 287 - 304.

Marinică, I., Marinică Andreea Florina. (2014). Considerations on desertification phenomenon in Oltenia, *Forum geografic. Studii și cercetări de geografie și protecția mediului*, XIII(2), 136-147.

Marinică, I., Marinică Andreea Florina. (2013). Droughty autumn of 2012 in the South-West of Romania, Air and water components of the environment. World Water Day 2013, World

Meteorological Day 2013, 22-23 March 2013, Presa Universitara Clujeana Publishing House, ISSN 2067-743, pp. 484-491.

Marinică, I., Marinică, Andreea Florina. (2008). The Heat Wave of July 2007 and its effects on the Biosphere. Muzeul Olteniei Craiova. Oltenia. Stud. Şi Com. Şt. Nat. 24: 211-220.

Marinică, I., Chimişliu, Cornelia. (2009). Considerations upon the Temperature Humidity Index in Oltenia in the Period 2000-2007, Muzeul Olteniei Craiova. Oltenia. Stud. şi Com. Şt. Nat. 25.

Nichol, J. (2009). An emissivity modulation method for spatial enhancement of thermal satellite images in urban heat island analysis. Photogrammetric Engineering & Remote Sensing, 75(5): 547-556.

Pérez Arrau, C. (2007). Cinq exemples de terrains de jeux synthétiques et de températures associées par une image thermique Landsat 5, Dicussion publique sur des terrains synthétiques a Westmount Park, Westmount, Canada.

Roşca, A., Roşca, Daniela. (2015). Considerations on the influence of micro urban islands to the temperature – humidity index in Craiova. *Forum geographic. Studii şi cercetări de geografie şi protecţia mediului*. XIV(1), 41-50. doi:10.5775/g.2067-4635.2015.012.i.

Sham, J. F.C., Lo, T. Y., Shazim Ali Memon. (2012). Verification and application of continuous surface temperature monitoring technique for investigation of nocturnal sensible heat release characteristics by building fabrics, Energy and Buildings 53 (2012), pp. 108 – 116.
http://dx.doi.org/10.1016/j.enbuild.2012.06.018.

Stathopoulou, M., Cartalis, C., Andritsos, A. (2005). Assessing the thermal environment of major cities in Greece. In: Proc. 1st International Conference on Passive and Low Energy Cooling for the Built Environment, Santorini, Greece.

Stathopoulou, M., Synnefa Afroditi, Cartalis, C., Santamouris, S., Karlessi, T., Akbari H. (2009). A surface heat island study of Athens using high-resolution satellite imagery and measurements of the optical and thermal properties of commonly used building and paving materials, International Journal of Sustainable Energy, 28:1, pp. 59 - 76.

Synnefa, Afroditi, Santamouris, M., Livada, I. (2006). A study of the thermal performance and of reflective coatings for the urban environment. Solar Energy 80, pp. 968–981.

Synnefa, Afroditi, Santamouris, M., Apostolakis, K. (2007). On the development, optical properties and thermal performance of cool colored coatings for the urban environment, Solar Energy, 81, pp. 488–497.

Synnefa, Afroditi, Karlessi, Th., Gaitani, N., Santamouris, M. (2009). Measurement of optical properties and thermal performance of colored thin layer asphalt samples and evaluation of their impact on the urban environment, Second International Conference Countermeasures to Urban Heat Islands, Berkeley, CA, Environmental Energy Technologies Department E.O. Lawrence Berkeley National Laboratory.

Teodoreanu, Elena, Bunescu, Iulia. (2007). Thermal Comfort, Present Environment and Sustainable Development, nr. 1, Iasi, pp. 135-142.

Voogt, J.A. (2004). Urban Heat Islands: Hotter Cities, http://www.actionbioscience.org/environment/voogt.html, November 2004.

Voogt, J. A. (2002). Urban Heat Island. In Encyclopedia of Global Environmental Change, vol. 3. T. Munn (Ed), pp. 660 - 666 (Chichester: Wiley).

Voogt, J.A., Oke, T.R. (2003). Thermal remote sensing of urban climates. Remote Sensing of Environment, 86, pp. 370 – 384.

Weng, Q. (2009). Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. ISPRS Journal of Photogrammetry & Remote Sensing, 64, pp. 335 - 344.

http://www.accuweather.com/en/ro/craiova/287856/july-weather/287856

http://www.icess.ucsb.edu/modis/EMIS/

http://www.googleearth

http://www.urbanheatislands.com/bibliography

http://www.zytemp.com/infrared/application.asp

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The analyze of relationship between microclimate and microbial carbon-dioxide production in the soils of the Tapolca and Gömör-Tornai karst terrains, Hungary

János MÓGA[1,*], Klaudia KISS[1], Andrea BORSODI[2], Mária SZABÓ[1], Daniela STRAT[3], Bódai BARBARA[1]

[1]Eötvös Loránd University Geography and Earth Science Institute, Pázmány P. sétány 1/c, 1117, Budapest, Hungary
[2]Eötvös Loránd University Institute of Biology, Department of Microbiology, Pázmány P. sétány 1/c, 1117, Budapest, Hungary
[3]University of Bucharest, Faculty of Geography, 1 Nicolae Bălcescu Blvd., Bucharest, Romania

* *Corresponding author*: janosmoga12@gmail.com

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Abstract

In the karst areas, the epikarst system is a very sensitive environment, due to its position at the interface between soil and vadose zone. The epikarst is a weathered zone that develops as a re-sult of both abiotic and biotic process-es. In this paper we present the result of the complex investigations of epikarst zone which overlap dolines within two typical karst areas (Gömör-Torna and Tapolca) from Hungary, based on multi-criteria analysis tech-niques (microbiological activity as-sessed as biomass amount and CO2 production, seasonality of air and soil microclimate, slope orientation and exposition), in order to reveal control factors of karst processes, the territori-al and local distinctions of karst disso-lution that occur in the epikarst zone. The data were compared, taking into account the human activities' impact on both sampled study areas. After four years of monitoring, the results show that there are significant season-al and diurnal variations of physical, chemical and biotic parameters of soil that cover and affect the epikarst zone. Spatial variations of these parameters were recorded as well.

Keywords: *epikarst, microclimate, soil, CO_2 pro-duction,, karst corrosion*

Rezumat. Analiza relației dintre microclimat și producția microbială de dioxid de carbon din sol în zonele carstice Ta-polca și Gömör-Tornai, Ungaria

În cadrul zonelor carstice, sistemul epicarstului este un mediu complex și senzitiv care se dezvoltă ca interfață între profilul de sol și zona vadoasă. Epicarstul este o zonă de alterare/meteorizare a rocilor carbonatice formată prin procese abiotice și abiotice. În această lucrare sunt prezentate rezultatele unei investigații complexe care a avut loc în epicarstul ce corespunde dolinelor din cadrul a două regiuni carstice (Gömör-Torna și Tapolca) din Ungaria folosind tehnici de analiză multicriterială în vederea identificării factorilor de control a proceselor carstice precum și pentru a determina diferențieri teritoriale și sezoniere ale proceselor de disoluție specifice epicarstului. Datele obținute au fost comparate luând în considerare gradul de impact antropic din cele două zone carstice eșantionate. După patru ani de măsurători și observații, rezultatele obținute indică existența variațiilor sezoniere, diurne și spațiale semnificative ale parametrilor fizici, chimici și biologici ai învelișului de sol care acoperă și influențează epicarstul din zonele carstice studiate.

Cuvinte-cheie: *epicarst, microclimat, sol, producția de CO_2, coroziunea carstului*

Introduction

The epikarst system is an extremely complex and sensitive environment which acts as a transition zone between the topographic surface or soil cover and the vadose zone of the karst landscapes. Initially, the term epikarst, coined by Mangin (1973), was defined as the upper aquifer of the vadose zone. Ac-cording to Williams (1983), the epikarst is the "sub-cutaneous zone", namely, the upper weathered layer of rock beneath the soil but above the permanently phreatic zone that acquires a secondary permeability, due to significant chemical solution. In fact, the term "subcutaneous zone" is an English adaptation of several French synonym terms (sub-superficial, sub-epidermic, karst cutane) which were consecrat-ed by the French geographers, (Ciry 1959, Birot 1966, Bakalovicz, 2014) in the middle of the twentieth century.

At the beginning of the 21st century, Bakalovicz (2014) stated that epikarst is the "skin" of karst and the soil should be considered as entirely part of it. Therefore, contrary to opinion of Williams (1983), the "epikarst can be easily defined by its hydrologic functioning, rather than by a set of landforms", the epikarst is where water storage takes place. There are a multitude of factors that act to the epikarst formation, abiotic and biotic (Mangin, 1973; Jakucs, 1980; Bárány, 1998; Klimchouk, 2004), but it is stated that the epikarst zone develops the best in pure crystalline limestone or marble where it can reach a thickness of 10 m (Williams, 2008). However, the most comprehensive definition of the epikarst was proposed during the Karst Water Institute, in 2003 (Jones, et al., 2004; Jones, 2013).

Carbon dioxide is a key chemical that drives dissolution in the carbonate karst areas. The main source of carbon dioxide from karst systems is the soil which formed on the carbonate terrains (Ford & Williams, 2007). The principal amount of carbon dioxide from soil is biogenic (Faimon et al., 2012). It is produced by the respiration of soil biota, both autotrophs and heterotrophs (Kuzyakov & Larionova, 2005; Kuzyakov, 2006; Song et al., 2017), but its production may depend on several factors, such as temperature and soil moisture, soil profile depth, soil structure, organic matter content, availability of soil nutrient, total rainfall, solar radiation and photosynthesis, but also various anthropogenic factors, such as soil tillage, or artificial change in vegetation cover (Dijkstra et al., 2013; Blecha & Faimon, 2014). Also, there is a seasonal variation of CO_2 concentrations, the highest values are in summer and lower values occur in autumn/winter (Faimon et al., 2012).

The production of CO_2, as a quantitative measure of the microbial activity of soil, is used since the mid-nineteenth century, but the measurement of microorganism respiration have to be correlated with other parameters of microbial activity, such as organic matter content, nitrogen and phosphorus transformations, pH, changes in soil weight (Stotzky, 1965). Since then, various methods have been developed in order to quantify accurately the microbial soil activity (Stotzky, 1965; Bauer et al., 1991; Solaim-an, 2007; Creamer et al., 2014; Pal & Marschner, 2016).

In Hungary, studies on karst soils and epikarst, including microbial activity, have been performed by Keveiné & Zámbó (1986), Zámbó (1998), Zámbó & Telbisz (2000), Zámbó & Ford (2003), Szili-Kovács & Török (2005), Szili-Kovács et al. 2009, Keveiné Bárány (2009), Knáb et al. 2010,2012.

Materials and Methods

In each study, karst areas were chosen dolines as characteristic sites for in situ measurements and soil sampling (Fig. 1).

Figure 1: Field measurements at Tapolca karst area. In the back ground there are basalt-capped buttes

Within the Gömör-Torna karst, the sites for surveying were located in three division of it: the Aggtelek Plateau, Alsó-hegy and Szilice Plateau (Fig. 2).

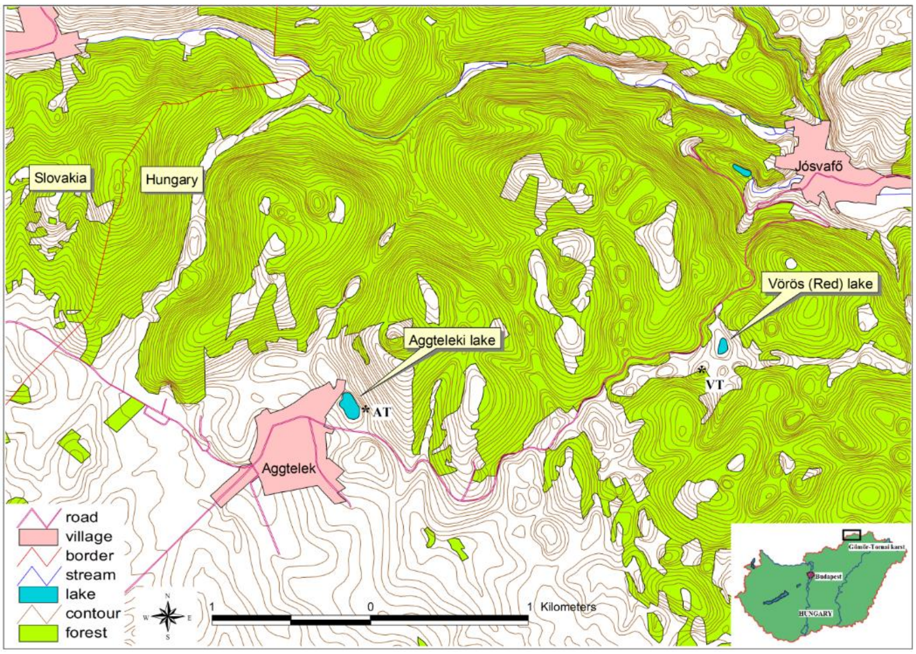

Figure 2: The locations of the measurement points in the area of Aggtelek Plateau: AT- Lake Aggtelek, VT – Lake Red (Vörös)

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The first one (AT) was established close to Lake Ag-gtelek, formed in a former doline and located in the western part of the karst plateau (Fig. 3). For the second one (VT) a doline was chosen, close to Lake Vörös ("lake red").

Figure 3: Lake Aggtelek (AT), one of the se-lected measurement points from Ag-gtelek Plat-eau

Then, the next soil sampling and microbiological surveys were carried out in dolines that are next to the Béke Cave (BT), an environment without the disruptive effects of human activities. The fourth site was established close to Lake Derenki (DT), in Alsó-hegy, a semi natural area, both with barren and covered karst.

The last site was located in the vicinity of Szilice village (Szilice-Plateau, Slovakia), on a downhill, next to Lake Papverme (PvT).

There were also five sampling sites in the Tapolca karst terrain. They were distributed in the middle part of Tapolca karst, along the line that links the small lakes that are supplied by karstic springs and precip-itations (Fig. 4): Lake Pokol (PoT), Alsó-Cser (ACsT), Zalahaláp doline (TA), Felső-Cser (FCsT), the doline at the forest margin (VAD), and illegal waste deposit (IH).

For each study site, soil profiles were made and examined, in order to describe and identify the soil types. Soil samples were taken for chemical and min-eralogical analyses.

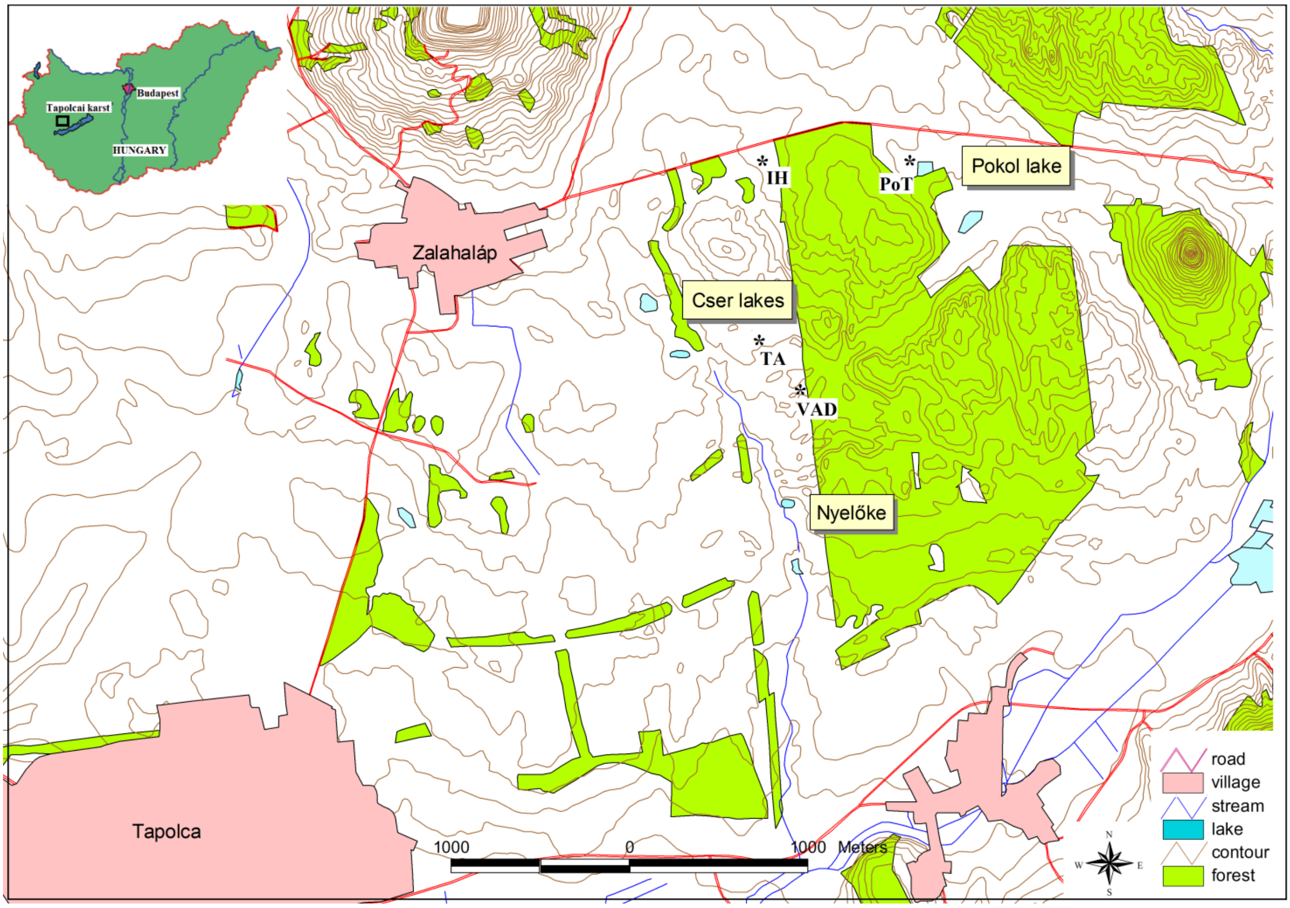

Figure 4: The locations of the measurement points in the Tapolca karst area: IH – Illegal garbage deposite, TA – Tapolca (Zalaháláp) doline, PoT – Hell (Pokol) lake, VAD – Dolines at the forest margin

Then, rain-stimulated experiments were set up on the soil monoliths. The soil solution was collected, in order to measure pH, carbonate and hydro carbonate content. The determination of the water samples' bicarbonate content was accomplished according to the valid Hungarian Standards Institution (MSZT 448-11: 1986). Microbiological parameters of soil solution were analyzed for the characterization of microbial-influenced karst corrosion.

In situ measurement data for the characterization of microclimate were recorded by a mobile weather station every two hours: air temperature (at 0, 20 and 100 cm high above ground), the relative moisture of air, the evaporation at 20 and 100 cm above ground, wind speed and wind direction every two hours. Soil temperature, soil pH and carbon dioxide concentration were also measured.

Soil temperature was recorded by a conventional mercury soil thermometer, 0.1 °C accuracy Pt, at 5 and 20 cm deep. The soil moisture content was determined with the help of an Eijkelkamp 14.22 Soil Moisture Measuring System with Gypsum Blocks meter, while the pH of soil and soil solution was measured by a Hanna pH meter.

The measurement of the carbon-dioxide concentration of the soil air, which reveals microbial respiration, has been achieved with the help of Gastec Model GV-100 car-bon-dioxide pump, which contains 2L and 2LL-type sampling tubes/pipes, side by side/in parallel with the microclimate measurements, in the same locations.

In every doline that was selected as a sampling site, observations and measurements were made and samples were taken from the north side, south side and bottom to find out the effect of exposure. The measurements were accomplished through 2 hour-long intervals for a whole day, in different seasons. The applied method was convenient for the demonstration of the differences between locations, between the diverse depths along the soil profiles, and between the daily dynamics and seasonal distinctions.

In this way, connections were searched between the microclimatic phenomena and the values/rates of soil climate (temperature and moisture of the soil, pH, carbon-dioxide concentration), to identify the spatial distinctions, diurnal and seasonal changes.

Samples for microbiological investigation were cultivated onto three different culture media, and colonies with various morphology were isolated. After isolating community DNA from the soil samples, clone libraries were constructed. The phylogenetic identification of the bacterial strains and molecular clones was based on the 16S rRNA gene sequence analysis.

In karst soils and in cover sediments the sampling was carried out partly by drilling holes, and partly by the extraction of large ground monoliths combined with rainfall simulation tests. The physicochemical (grain composition, pH, humus and carbonate content, etc.) and microbiological parameters of the soil solution which percolates through the ground monoliths were compared. Measurements were carried out and assessed according to the appropriate procedures of the MSZT (Hungarian Standards Institution).

This paper presents the partial result of the complex investigations of epikarst zone which overlap dolines within two typical karst areas (Gömör-Tornai and Tapolca) from Hungary based on multi-criteria analysis techniques.

Results and Discussions

Study Areas

Our studies were performed within two different karst regions, in terms of natural environment characteristics and the degree of anthropogenic impacts: Gömör-Torna karst system and Tapolca karst system. The aim was to compare the developmental karst processes between the two areas, according to the local natural factors and anthropogenic impacts.

The Gömör-Torna karst area is located in north-eastern Hungary, along the Hungarian-Slovakian border, between the Sajȯ and Bȯdva rivers. The sites for measurements and sampling tests were selected in Aggtelek Plateau – a subunit of the Gömör -Torna karst area and part of the Aggtelek National Park (which was designed as UNESCO World Heritage) – and Alsȯ-hegy ("Lower Mountain"). Within the Aggtelek National Park over 250 caves were inventoried, including the 26 km-long Baradla-Domica cave system, a cross-border cave that is famous for its outstanding speleothems.

The Aggtelek Karst consists of mainly Middle Triassic limestones (Veress & Unger, 2015). On the surface of the plateau the perceive karst features are dolines and sinkholes. Several doline lakes, blind valleys and dry valleys with a series of dolines complement the karst landscape.

In the area, the climate is humid continental with a long summer and a strong mountainous influence (Tanács, 2011). The average mean annual air tempera-ture values vary between 8.5°C and 9.1°C, and the air humidity is between 90%. The amount of annual precipitation is around 620 mm (Tanács, 2011). Natu-ral vegetation consists of forests. Dry oak-forests cover the limestone ridges of the karst plateau. Dominant species are the sessile oaks (Quercus petraea (Matt.) Liebl.), followed by the Turkey oak (Quercus cerris L.), field maple (Acer campestre L.), hornbeam (Carpinus betulus L.), and common ash (Fraxinus excelsior L.) (Kotroczó, et al., 2007). Beech stands (Fagus sylvatica L.) occur in the hollows and deeper valleys. The presence of the black pine (Pinus nigra J.F. Arnold) is probably the result of plantation

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works from the beginning of the 20th century (Tanács, Szmorad, & Bárány-Kevei, 2007).

Studies on chemical composition and soil taxonomy from Gömör-Torna karst terrains started in the second half of the 20th century (Zámbó, 1986, 1998; Zámbó-Telbisz, 2000). Following Bridges's (1978) and Stefanovits's (1981) methods, alongside with other particular in situ and laboratory tests, the prevalent soils that were described are rendzina and red-earth soils (Zámbó, 1986, 1998; Zámbó-Telbisz, 2000).

Later, based on the results of studies, regarding the correlation between three species composition of forests and soil proprieties from Haragistya-Lófej forest reserve and Szilice Plateau (Tanács-Barta, 2006; Tanács, et al., 2007), subtype soils were dis-criminated according to the World Reference Base for Soil Resources (Barta, et al., 2009), which was a similar approach to classification from the Slovakian part of Gömör-Torna karst terrain (Rozložnik-Karasová, 1993). Mineral types and content analysis of soils from this region are given by Knauerné (1992) and Fekete et al. (2006, 2008).

Compared to the Gömör-Torna karst, Tapolca karst area is only a small region. It is located in the western part of the Transdanubian Mountains, be-tween Balaton Uplands and Keszthely Mountains. The Tapolca karst system coincides in part with a sedimentary basin, mainly made up of quasi-horizontal Sarmatian limestone strata that are called Tinnyei Formation (Budai, et. al., 1999). It is com-posed of various clayey and calcareous layers, thus water permeable and impermeable layers are altering in it. Pleistocene-Holocene alluvial-diluvial sandy and clayey deposits superimpose Sarmatian limestone discontinuously. Consequently, patches of open karst alternate with covered karst, leading to a mosaic-like pattern of Tapolca karst terrain.

The Sarmatian limestone that generated the nowadays general topographic surface with 120-160 m elevations is underlaid with Main Dolomite For-mation and Sédvölgyi Dolomite Formation (Budai, et al., 1999). In the northern part of the Tapolca basin, dolomite formations outcrop as inselbergs above the surrounding area that has 120-160 m altitude. Therefore, this area, which displays remnants of Cretaceous cone karst peneplain, is the most diversified morphological part of the Tapolca karst area, where both paleokarst and recent landforms occur equally (Büki, et al. 2011).

Small and shallow dolines have been developed mostly on the brink of dolomite and Sarmatian limestone which explains why they are arranged in rows in some places and others through merger evolved into uvalas (Futó, 2003). Many fossilized dolines, formed during a tropical climate, are filled with red clay and bauxite.

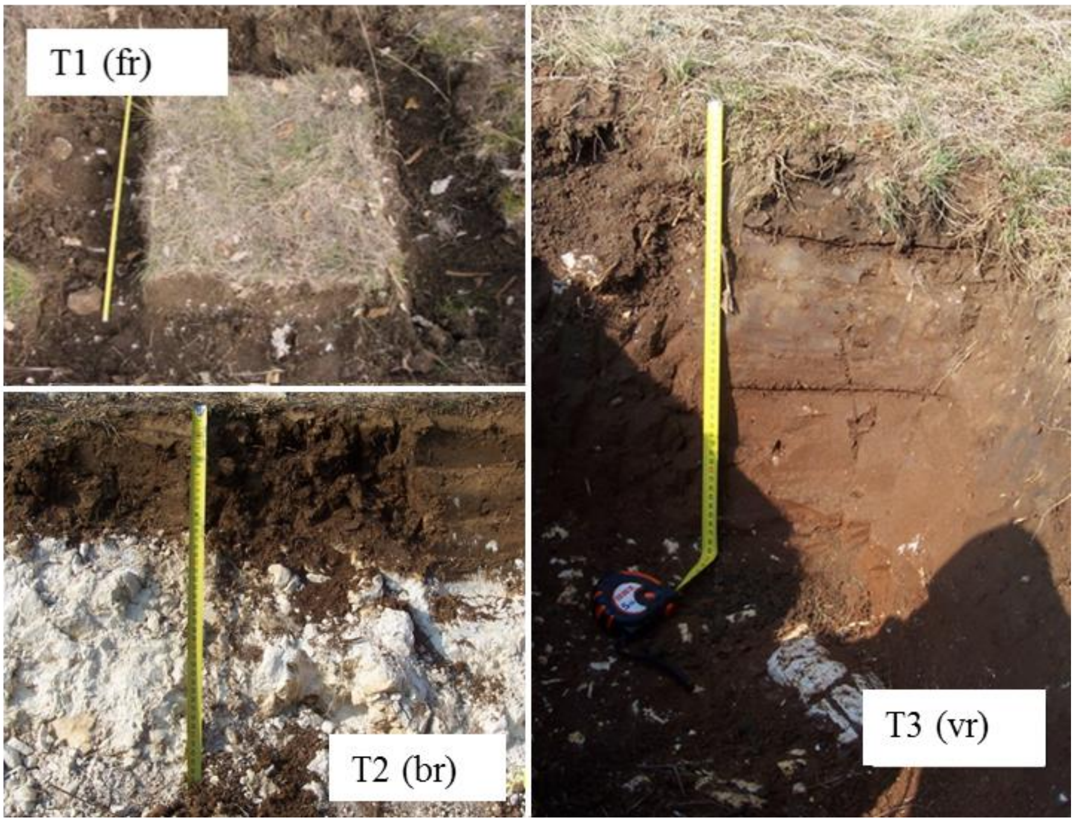

Figure 5: Soil profiles on the Tapolca-karst. T1 (fr) - black rendzina, T2 (br) - brown rendzina, T3 (vr) - red clay rendzina

In the porous-structured limestone field, the level of karst water runs along close to the surface, during the whole year, which emerges to the surface when the water is high, feeding/supplying periodic karst springs.

Three periodic-watered lakes (Alsó, Felső-Cser, Névtelen) had been evolved close to Zalahaláp, in a karst hole, coated with watertight layers. In the northern side of the Tapolca-karst terrain, there is Lake Pokol (Hell). Its depression is incised on a basalt-bordering karst field and fed by a small stream dominantly during the rainy period of the year.

Regarding the soil types, there are no peculiar studies. According to the geological map and 1: 100.000 scaled Agrotopo-maps (www.mta-taki.hu), the soil cover from Tapolca karst terrain consists of rendzina types, leptosols and brown forest soils.

In the vicinity of Lake Cser, protosoils and weakly soiled sediments (Pannonian sand, sandy and pebbly lacustrine sediments) are dominant. Red-clay sediments with bauxite fill paleokarst recesses and dolines, whose bottoms are overlaid with colluvium (Móga, et al., 2011). Highly eroded soils and the rocky surface are significant in the area of flat terrains.

Soil profiles in the karst terrains

The results of mineral content and chemical characteristics of soils from the Tapolca Karst ter-rains were compared to those on the Aggtelek karst terrains (Knauerné, 1992). Three typical soil profiles (T1, T2, and T3) were analyzed from morphological and chemical point of view (Fig. 5). Therefore, the clay and loam fraction of the sample taken from three typical soil profiles (T1, T2, T3, Fig. 6) of dolines from Tapolca are similar to the soil profiles of Ag-gtelek. Also, these soils contain sand fractions in a few percent, due to Pannonian sediments which cover the surface in patches. Each tested soil sample had carbonate content in variable amounts. The hu-mus content was the highest (6.26%) in the black rendzina (T1), but this value is still behind the mini-mum rates of 7-8% that were recorded for rendzina subtypes in the Carpathian basin, according to Kiss records (2012). The pH values of all rendzina types are higher than 6.5 units, and their hydrolytic acidity is minimal. Hargitai's Q value of two rendzina types (T1, T2) is higher with two units than the red-clay soils' in Aggtelek (Knauerné, 1992). This fact shows the formation of humic substances (Buzás, 1998), which are related to the fields characteristics. There-fore, it can be explained with dissimilarity of the natural vegetation and the water type of the soil.

Based on the cluster analysis that included 52 rendzina profiles performed by Kiss (2012), the clas-sification of the soils of the Tapolca-karst terrain into rendzina types is not unambiguous. The mor-phological properties and weak structure of the pro-file (Fig. 6), the depth of soil, and the sand content of the samples gave an intermediary position (in the case of T1, T2) between the leptosol and rendzina soils, because the humus content is lower compared to the rendzina typical soil.

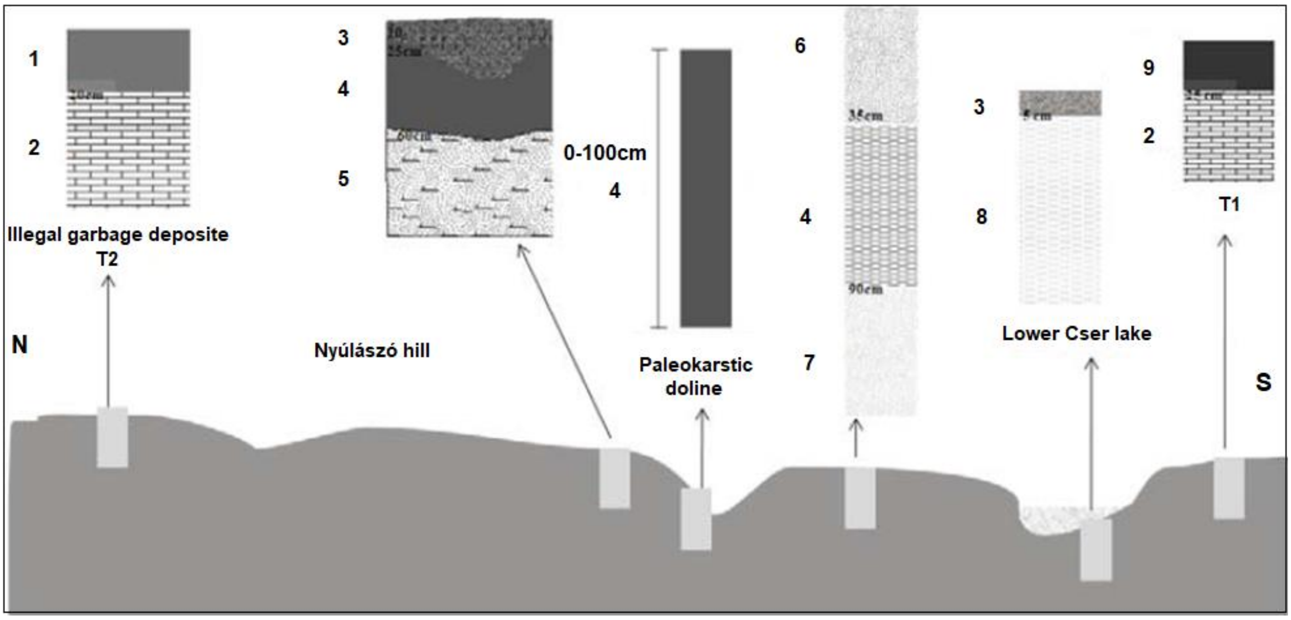

Figure 6: Theoretical N-S soil profile through the Tapolca karst terrain. T3 soil profile (which is not presented in this picture) is nearby T2 (See Fig. 5). 1- brown rendzina, 2 - limestone, 3 - humic level, 4 - red clay, 5 - coarse sand with high Ca CO_3 content, 6 - doline infill red clay, 7 - weak humic sand, 8 - lake sediment, sandy clay, 9 - black rendzina

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The classification of the T3 soil is even more problematic: the color and clogging of C layer, the appearance of the clay membrane in the profile reflects the red clayey origin. However it has a low acidity (pH > 7 value) and, because of the carbonate content of the upper layer, present cli-mate, fills a part in the recent development of the soil (water balance processes), beside the effect of the ballast-rock (dolomite, layer D).

Microclimate of atmosphere, soil air and soil proprieties

Climatic and microclimatic factors are important drivers in the activity of soil biota and implicitly they are responsible for carbon dioxide production and its amount from soil air (Jakucs, 1971; Zámbó, 2001; Keveiné Bárány, 2009). Also, climate is a mor-phogenetic factor in the control of erosion processes and weathering of rocks, however, in the karst sys-tem it is an ecological factor which provides the dy-namism of karst development (Keveiné Bárány, 1998, 2009). On the dolines surfaces from karst areas and closed recesses microclimate areas evolve, especially where exposure has a significant role in the spatial and temporal changes of the energy that precede distinctions. All of these facts have an influence on the formation of air and soil temperature, the evolu-tion of local distinctions of soil moisture, the plant-cover of dolines, the microbial activity of the soil and finally, the formation of spatial differences in the karst corrosion processes of karst fields (Keveiné Bárány, 2009). Measurements performed within do-lines from both Tapolca and Gömör-Torna karst dur-ing 2009-2012 revealed that there are microclimate differences induced by the morphometry and mor-phology of dolines. It revealed a significant discrep-ancy in terms of diurnal air temperature and evapo-transpiration that is associated with the exposure of dolines.

Our simultaneously-accomplished measure-ments performed in sampled dolines from Tapolca, next to Lake Vörös, revealed the effect of the vegeta-tion coverage – rocky grassland versus forest – on the microclimate of the dolines. In contrast to the previ-ous site, the whole area of the Derenki dolines is covered by forest, which dimmed the distinction of temperature values among the measuring spots. Thus, during the summer, the results show that in the dolines, next to Lake Vörös, the highest air tem-perature (at 20 cm above ground) and the largest diurnal temperature fluctuations (amplitude) have been measured at the northern edge (VTE) of the dolines (i.e. on the side exposed to the south) that are covered by rocky-lawn. During a 24-hour day, air temperature ranged from 23 °C to 31°C. By the reason of the shadow effect, lower and much more moderate temperature values have been recorded at the bottom (VTA) and at the northern exposure stations (VTD) of the dolines. However, the two stations' values hardly differed from each other (21-25°C). Regarding the soil temperature, they were recorded similar var-iations depending on position and exposure of the sides of doline depressions. At 5 cm depth, the soil temperature was lower than the air temperature, as well as the amplitude (VTD: 19-20°C, VTE and VTA: 16-20°C) (Fig. 7).

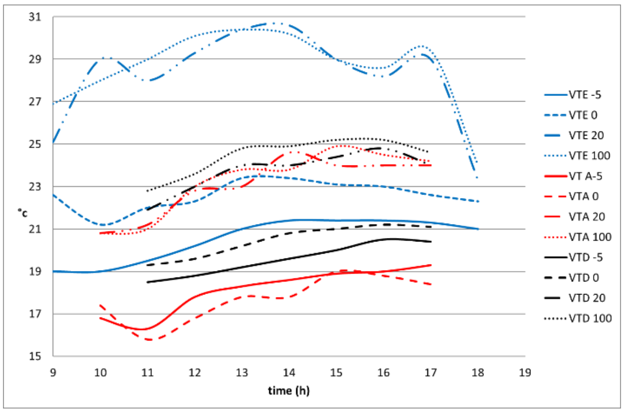

Figure 7: The temperature variation in the dolines above ground surface and with the depth of soil, located in the vicinity of Lake Vörös

In Derenki site (DT) from the Gömör-Torna karst terrain, the recorded air temperature values were lower (17-20, 5°C) at all three measuring stations (DTD, DTA, DTA), than those from Vörös doline site (VT). Soil temperature measured at 5 cm depth (17-19°C) was much closer to air temperature at all three stations (DTD, DTA, DTA) than in Vörös doline site, and showed a similar trend, next to the low air temperature values. It should be noticed that temperature values, air and soil, are slightly higher at the side dolines with southern exposure than those with northern exposure (Fig. 8).

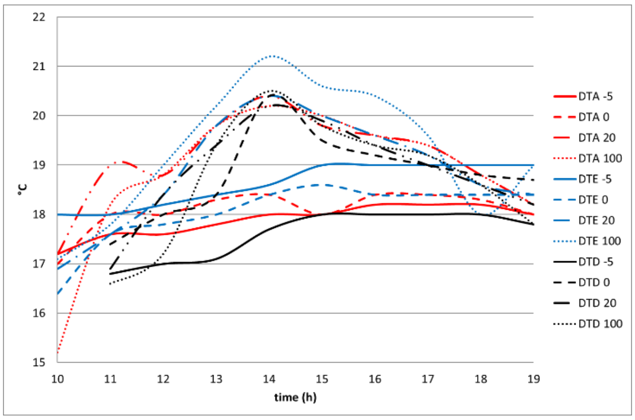

Figure 8: The diurnal temperature variation in Derenki dolines from from the Gömör-Torna karst terrain, NV Hungary

By comparing microclimate data recorded in Vörös doline site (VT), Tapolca karst terrain, with those in

Derenki site (DT), Gömör-Torna karst terrain, it is obvious that the elevation of the study are-as, the certain morphology of dolines, which consists of large-sized, flat bowl-shaped dolines in Derenki and the small, sheer-sided dolines, next to lake Vörös, along with the complexity of vegetation cover, play an important role in the development of dis-tinct microclimates, although it is difficult to identify which of the factors is defining for temperature-shifting.

The seasonal and diurnal changes of the carbon dioxide concentration in the soil air

Measurements of CO_2 content in soil air on study sites show a great variance between them, according to local microenvironment from each station and the depth at which the measurements were made. Overall, the recorded values, measured by a 2L-type pipe method, ranged from 100 ppm up to 30 000 ppm or 3%.

Within dolines from Vörös doline site (VT), the maximum values of the soil air's CO2 content (>3%) has been always measured on the bottom, at 20 cm depth in the soil (VTA) while the lowest values (1-2000 ppm) were recorded at 5 cm depth in the soil (Fig. 9).

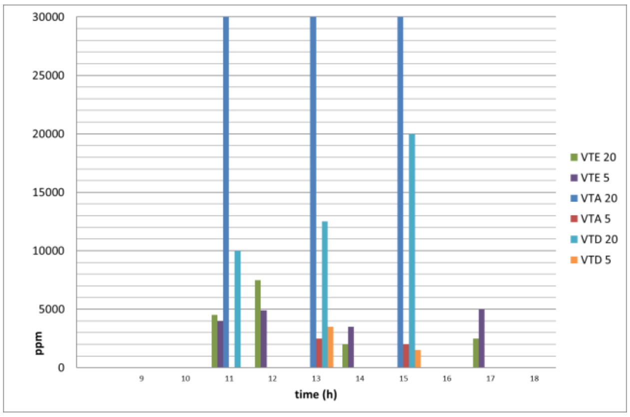

Figure 9: The change of the CO_2 concentration of soil air at the VT (Vörös doline) measuring spot

On the cooler, sloppy southern sides (VTD), similarly to the dolines bottom, the CO2 concentrations were above 10000 ppm (1%). The concentration values of CO2 soil air at Tapolca were similar to the dolines from Derenki site (DT), but were lower than those from Aggteleki karst terrain. The difference is supposedly caused by different physical soil characteristics and microbial activity (Fig. 10).

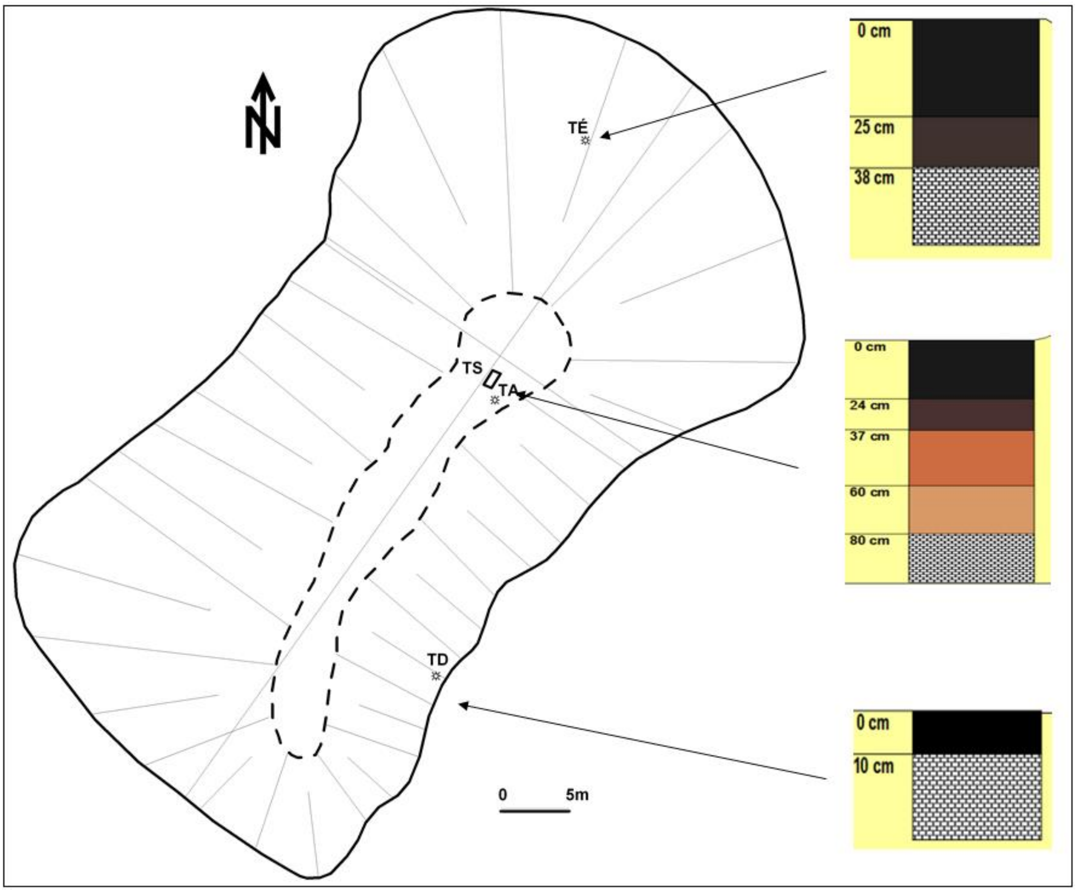

Figure 10: The sketch of a doline (Tapolca doline – TA) and location of measuring points - Tapolca karst area. For each point is illustrated the soil profile: TD – southern side of the doline, TS – soil profile in the bottom of doline, TÉ – northern side of doline

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At 80 cm depth in the soil from bottom dolines, carbon dioxide values ranged between 1-2%, which represent about half or two thirds of the values determined at 20 cm soil depth. Therefore, the gained results of the field measurements in both karst study areas are in good accordance with literature data (Jakucs, 1971; Zhang & Zhang, 1983) and they clearly certify that the carbon-dioxide production rate in the soil does not increase directly in proportion to the depth, but has a maximum value at the depth of 20-40 cm.

Seasonal measurement carried out in all study sites also validate that the CO2 concentration values show increasing tendency in the daytime, if there are no circumstantial disturbing factors, mainly weather extreme events. However, the highest carbon-dioxide concentration was recorded during late afternoon and evening. This tendency occurred more conspicuously in the case of carbon-dioxide measurements that were made at deeper levels of soil.

The analysis of the relationship between microclimate and microbial carbon-dioxide production in soil with field measurements

Due to the changing weather conditions of July 30, 2011 (high air temperature and sunny sky followed by a rain storm during the early afternoon) during the field trip in Tapolca karst area, it has been possible to investigate the relationship between quickly changing microclimate and CO2 concentration in soil air as a result of microbial activity. The hourly evolution of air temperature at three and soil temperature at three different above topographic surface and at 5 cm soil depth shows a direct correlation between increasing temperature and CO2 content in the first 5 cm of the topsoil (Fig. 11).

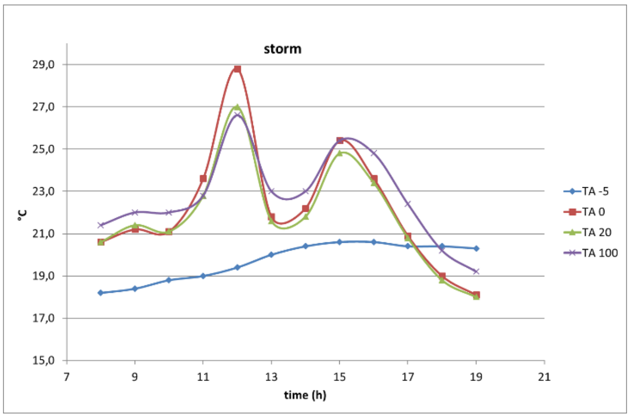

Figure 11: The diurnal variation of air and soil (blue line) temperature within the Tapolca doline (Zalahaláp) (TA)

The upward linear trend of CO_2 concentration lasted until the storm, and then it fell back during the rainstorm. After that, CO_2 concentration raised again due to of the influence of late afternoon warming which followed the rain episode. The values, measured in three different soil depth reveals that a disturbing effect of weather factors was detectable in the first 20 cm soil profile. As it can be seen in Figures 11 and 12, the effect of temperature decrease on microbial activity was experienced in the first 5 cm of the soil profile. Furthermore, the cooling effect of the rain on the soil which slowed down microbial activity was supplemented by the anoxic environment created by the replacement of air from soil pores with water and depletion of available oxy-gen for aerobic bacteria that are responsible for organic decomposition and main CO_2 producers.

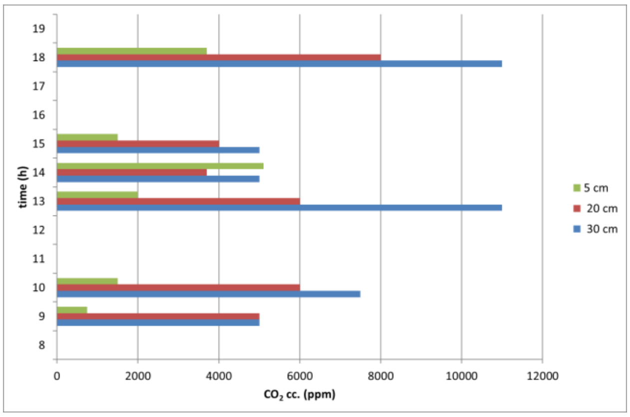

Figure 12: The change of the CO_2 concentration of soil air into TA doline during a summer rain storm

The results of microclimate and CO_2 measurements, performed in parallel, support the previously recognized fact that meteorological factors affect the microbial CO2 production from soil (Jakucs, 1971; Keveiné & Zámbó, 1986; Zámbó, 1998; Zámbó & Ford, 2003; Szili-Kovács & Török, 2005; Szili-Kovács, et al., 2009; Keveiné Bárány, 2009; Knáb, et al., 2010; Knáb, et al., 2012; Knáb, et al., 2018). The alteration of sunny, cloudy and rainy weather may result in significant temperature changes in the layers, close to the surface. Increase in air and soil is accompanied by the intensification of enzymatic activity of soil bacteria and simultaneously, the rate of carbon-dioxide production.

Although there is a great diversity of soil organisms (plant roots, alga, protozoa, invertebrates), whose breathing contributes to CO2 content of the soil atmosphere; their particular contribution is difficult to differentiate and quantify. Consequently, the assessment of the respiration of microorganism decomposing soil organic matter is a suitable method for determination of CO2 supply to soil.

The daily dynamics and depth dependence of the carbon-dioxide concentration from soil air

The measurements carbon dioxide content of soil atmosphere within a brown forest soil about 80 cm thick that has developed on the bottom of a dolines from Tapolca confirms the results of previous examinations. There is an increasing trend of the Carbon dioxide concentration in the topsoil and then, gradually, the organic matter content is diminishing along with all physical and chemical soil proprieties. Thus, in the tested soil profile, from the topographic surface towards the subsoil evolution (Fig. 13), the carbon-dioxide concentration of soil atmosphere shows an increase from 6000 ppm at 5 cm depth to 15 500 ppm at 15 cm depth, and only 1500 ppm at a depth of 30 cm.

Figure 13: A 80 cm deep soil profile (TS) in the Tapolca (Zalahaláp) doline (TA) with values of the measured CO_2 concentration at different deep level (See Fig. 12)

Then, the values show slight oscillations between 1500 and 2000 ppm that were interrupted by a peak (8000 ppm) at 35 cm depth, which may be a consequence of the root level of the plants (Fig. 14).

These results were strongly supported by the biomass determinations that were also made by the microorganism diversity.

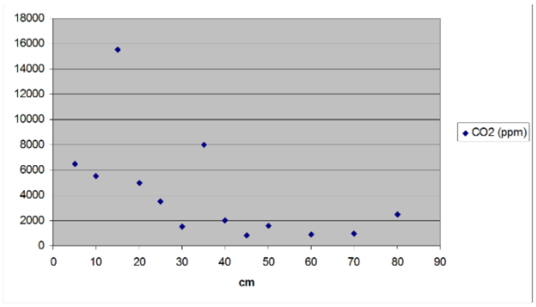

Figure 14: The changes of CO_2 concentration of the soil air in the TA doline with the depth of soil

The biomass decreases from the topsoil to the bottom, and the compound of microorganism communities are strongly different. In addition, the available oxygen gas involved in aerobic respiration decomposition processes at a depth of 70- 80 cm of soil profile is very low.

Conclusions

In order to understand the effect played by the different soil types on karst corrosion processes, we measured the microclimate on the field and the amount of CO2 in the karst soil. We defined the spatial and temporal quantitative changes of CO2 concentration of microbial origin. We investigated the correlation between microclimate, surface coverage, exposure, soil depth and the microbial activity (CO2 production). In every case, we measured the highest values of the CO2 concentration in the bottom of the sink hole –15-20 cm. We wanted to verify the de-pendency on depth, as well. Starting from the sur-face to downwards, we found out that the carbon-dioxide production rate in the soil does not increase directly in proportion to the depth, but has a maxi-mum value at the depth of 20-40 cm. These results were strongly supported by the biomass determinations that were also made by the microorganism diversity. The biomass decreases from the topsoil to the bottom, and the compound of microorganism com-munities are strongly different. Our measurement states that the meteorological factors also affect the microbial CO2 production from soil. According to our measurements, the amount of CO2 concentration showed a growing tendency during the day. We measured the highest CO2 concentration late in the afternoon. During the evening, as the temperature dropped, the concentration of CO2 dropped, as well. The alteration of sunny, cloudy and rainy weather may result in significant temperature changes in the layers, close to the surface. Increase in air and soil is accompanied by the intensification of enzymatic activity of soil bacteria and simultaneously, the rate of carbon-dioxide production.

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Authors contribution

The research of the epikarst has been carried out in teams, where the researchers participated according to their profession and skills. J. Móga fulfilled the geomorphological studies and field measurements, the soil field and laboratory works were led by K. Kiss and M. Szabó. D. Strat participated in the hydrological and ecological field investigations. The microbio-

logical and laboratory investigations were coordinated by A. Borsodi. K. Kiss, D. Strat and B. Barbara have contributed in the editing of illustrations and main text.

References

Bakalowicz, M. (2014). The epikarst, the skin of the karst. Karst Waters Institute Special Publication 9.https://www.researchgate.net/publication/267426221

Barta, K., Tanács, E., Samu, A., & Keveiné, B. I. (2009). Hazai rendzinák megfeleltetése a WRB nemzetközi talajosztályozási rendszerben. Agrokémia és Talajtan, 58(1), 7-18.

Bauer, E., Pennerstorfer, C., Holubar, P., Plas, C., & Braun, R. (1991). Microbial activity measurement in soil — a comparison of methods. Journal of Microbiological Methods, 14(2), 109-117. doi:10.1016/0167-7012(91)90040-W.

Bárány Kevei, I. (1998) Geoeocological system of karst. Acta Carstologica, 27(1), 13-25, Ljubljana.

Birot P., 1966, Etude de l'usure d'un versant calcaire sous un climat tropical humide: in Macar, P., (ed.), L'evolution des versants, Coll. Internat., Univ. Liege, 69-74.

Blecha, M., & Faimon, J. (2014). Karst soils: Dependence of CO2 concentrations on pore dimension. Acta Carstologica, 43(1), 55-64.

Bridges, E. M. (1978) World Soils, 2nd edition. Cambridge: Cambridge University Press, 128 pp.

Budai, T., Császár, G., Csillag, G., Dudko, A., Koloszár, L., Majoros, Gy. (1999) Geology of the Balaton Highland: Explanation to the Geological Map of the Balaton Highland, 1:50.000. Geological Institut of Hungary, Budapest (Hungarian, English).

Büki, G., Knab, M., Karoly, M., Móga, J., & Borsodi, A. (2011). Osszehasonlito diverzitas vizsgalatok a Tapolcai karst talajainak bakteriumkozossegein. Karsztfejodes, XVI, 143-155.

Buzás, I. (1988). Talaj- és agrokémiai vizsgálati mód-szerkönyv 2. A talajok fizikai–kémiai és kémiai vizsgálati módszerei. Budapest: Mezőgazdasági Kiadó.

Ciry R., 1959, Le role du sous-sol gele quaternaire dans le modele des plateaux bourguignons: Compte Rendus Academic Sciences Paris, v. 248, 2608-2610.

Creamer, R. E., Schulte, R. P., Stone, D., Gal, A., Krogh, P. H., Lo Papa, Murray, G., Winding, A. (2014). Measuring basal soil respiration across Europe: Do incubation temperature and incubation period matter? Ecological Indicators, 36, 409-418. doi:10.1016/j.ecolind.2013.08.015

Dijkstra, F. A., Carrillo, Y., Pendall, E., & Morgan, J. A. (2013). Rhizosphere priming: A nutrient perspective. Frontiers in Microbiology, 39, 600-606.

Faimon, J., Ličbinská, M., Zajíček, P., & Sracek, O. (2012). Partial pressures of CO2 in epikarstic zone deduced from hydrogeochemistry of permanent drips, the Moravian karst, Czech Republic. Acta Carstologica, 41(1), 47-57. Retrieved May 2008, 2018, from https://ojs.zrc-sazu.si/carsologica/article/viewFile/47/62

Fekete, J., Szendrei, G., & Csibi, M. (2006). Character-ization of Hungarian Red Soils. Agrokémia és Talajtan, 55, 29–38.

Fekete, J., Csib, I. M., & Stefanovits, P. (2008). Magyarországi vörösagyagok jelentősége, fontosabb talajtani jellemzőik. Talajvédelem (különszám), 585-594.

Ford, D., & Williams, P. (2007). Karst Hydrogeology and Geomorphology (Revised Edition ed.). Chichester, England: John Wiley & Sons Ltd. Retrieved May 15, 2018, from https://sudartomas.files.wordpress.com/2012/11/karsthydrogeologyandgeomorphology1.pdf.

Futó, J. (2003). Bakonyvidék. In: Székely, K. (edit) Magyarország fokozottan védett barlangjai. - Mezőgazda, Budapest, 339-344.

Jakucs, L. (1971). A karsztok morfogenetikája. A karsztfejlődés varienciái. Budapest: Akadémiai Kiadó, 310 pp.

Jakucs, L. (1980) A karszt biológiai produktum. Földrajzi közlemények, 28(4): 331-339.

Jones, W. K. (2013). Physical structure of the epikarst. Acta carstologica, 42(2-3), 311-314.

Jones, W. K., Culver, D. C., & Herman, J. S. (2004). Epikarst (Vol. Special Publication 9). Leesburg, Virginia: Karst Waters Institute.

Keveiné Bárány, I. (1998). Talajföldrajt. Nemzeti Tan-könyvkiadó, Kiadás helye: Budapest Nyomda.

Keveiné Bárány, I. (2009) A karsztok ökológiai rendszere. JATE Press Szeged, 121 pp.

Keveiné, I. & Zámbó, L. (1986). Study of relationship between bacteria activity in karstic soils and cor-rosion. Annales Universitatis Scientiarium Buda-pestinensis de Rolando Eötvös Nominatae, 20-21, 325-333.

Kiss, K. (2012). Vörösagyag-talajok vizsgálata az aggtelekikarszton (a béke-barlang vízgyűjtőjén). Karsztfejlődés, XVII, 89-103, Szombathely.

Klimchouk, A. B. (2004). Towards defining, delimiting and classifying epikarst: Its origin, processes and variants of geomorphic evolution. Speleogenesis and Evolution of Karst Aquifers, 2(1), 1-13. Retrieved May 13, 2018, from http://speleogenesis.info/pdf/SG5/SG5_artId3263.pdf

Knáb, M., Buki, G., Szili-Kovacs, T., Marialigeti, K., Moga, J., & Borsodi, A. (2012). Tenyesztesen alapulo es tenyesztestol fuggetlen molekularis biologiai diversitas vizsgalatok a Gomor-Tornai karszt talajainak bakteriumkozos-segein. Karsztfejlodes, XVII, 105-116.

Knáb, M., Kiss, K., Adam, L., Szili-Kovacs, T., Palatinszky, M., Márialigeti, K., Borsodi, A. (2010). Hazai epikarszt rendszerek talajaiban elofordulo mikrobakozossegek szerketenek es aktivitasanak osszehasonlito elemzese. Karsztfejlodes, XV, 35-48.

Knáb, M., Szili-Kovacs, T., Kiss, K., Palatinszky, M., Marialigeti, K., Móga, J., & Borsodi, A. K. (2012). Comparison of soil microbial communities from two distinct karst areas in Hungary. Acta Microbiologica et Immunologica Hungarica, 59(1), 91-105. doi:10.1556/AMicr.59.2012.1.10

Knáb, M., Szili-Kovacs, T., Marialigeti, K., Móga, J., & Borsodi, A. K. (2018). Bacterial diversity in soils of different Hungarian karst areas. Acta Microbiologica et Immunologica Hungarica, 23, 1-20. doi:10.1556/030.65.2018.002

Knauerné Gellai, M. (1992) Az Aggteleki Nemzeti Park térségéből származó vörösagyag-minták földtani-geokémiai vizsgálata. Kézirat, ANP.

Kotroczó, Z., Krakomperger, Z., Koncz, G., Papp, M., Bowden, R. D., & Toth, J. A. (2007). A síkfőkúti cseres-tölgyes fafajösszetételének és struktúrájának hosszú távú változása. [Long-term changes in the species compositionand structure of the Turkey oak-sessile oak stands at Síkfőkút (in Hungarian)]. Természetvédelmi Közlemények, 13, 93-107.

Kuzyakov, Y. (2006). Sources of CO2 efflux from soil and review of partitioning methods. Soil Biology & Biochemistry, 38, 425-448.

Kuzyakov, Y., & Larionova, A. A. (2005). Root and rhizomicrobial respiration: A review of approaches to estimate respiration by autotrophic and heterotrophic organisms in soil. Journal of Plant Nutrion and Soil Science, 168, 503-520.

Mangin A., 1973, Sur la dynamique des transferts en aquifere karstique. Proc. 6th Internat. Cong. Speleology, Olomouc, v. 3, 157- 162.

Móga, J., Kiss, K., Szabó, M.K., Borsodi, A., Kéri, A., Mari, L., Knáb, M., & Iván, V. (2011). Természeti és antropogén hatások vizsgálata a Tapolcai-karszt epikarsztos rendszerében. Karsztfejlődés, XVI, 185-201, Szombathely.

Rozložnik, M. & Karasová, E. (1993). Slovensky Kras. Banská Bystrica. 476 pp.

Solaiman, Z. (2007). Measurement of Microbial Biomass and Activity in Soil. In A. Varma, & R. Oelmuller (Eds.), Advanced Tecniques in Soil Microbiology (Vols. Soil Biology, 11, pp. 201-211). Berlin Heidelberg: Springer.

Song, W., Tong, X., Zhang, J., Meng, P., & Li, J. (2017). Autotrophic and heterotrophic components of soil respiration caused by rhizosphere priming effects in a plantation. Plant Soil Environment, 295-299. doi:10.17221/233/2017-PSE

Stefanovits, P. (1981). Talajtan. Budapest: Mezőgazdasági Kiadó.

Stotzky, G. (1965). Microbial respiration. In Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties (Vol. Agronomy Monograph 9.2, pp. 1550-1572). American Society of Agronomy, Soil Science of America. doi: 10.2134/agronmonogr9.2.c62.

Szili-Kovács, T. & Török, K. (2005). Szénforráskezelés hatása a talaj mikrobiális aktivitására és bio-masszájára felhagyott homoki szántókon. Agrokémia és Talajtan, 54: 149–162.

Szili-Kovács, T., Zsuposné Oláh, Á., Kátai, J., Villányi, I., & Takács, T. (2009). Talajbiológiai és talajkémiai változók közötti összefüggések néhány tar-tamkísérlet talajában. Agrokémia és Talajtan, 58: 309-324.

Tanács, E. (2011). Temperature and precipitation trends in Aggtelek karst (Hungary) between 1958 and 2008. Acta climatologica et chorologica, 44-45, 51-63.

Tanács, E. & Barta, K. (2006). Talajvizsgálatok a Hara-gistya-Lófej erdőrezervátum területén. Karszt-fejlődés, 11, 235-251.

Tanács, E., Szmorad, F., & Bárány-Kevei, I. (2007). A review of the forest management history and Present state of the Haragistya karst plateau (Aggtelek karst, Hungary). Acta Carstologica, 36(3), 441-451.

Veress, M., & Unger, Z. (2015). Baradla-Domnica: Large Cave System on the Hungarian-Slovak Border. In D. Loczy (Ed.), Landscapes and Landforms of Hungary (pp. 167-176). Springer International Publishing Switzerland. doi:10.1007/978-3-319-08997-3_20.

Zámbó, L. (1986). A talaj-hatás jelentősége a karszt korróziós fejlődésében (Aggteleki-karszt). Kandidátusi disszertáció, Kézirat. Budapest.

Zámbó, L. (1998). Talajtakaró. In: Baross, G. (ed.) Az Aggteleki Nemzeti Park (95–117). Budapest: Mezőgazda Kiadó.

Zámbó, L. (1998). The experimental examination of microbial origin corrosion aggressivity of karst soils. Acta Carsologica, 27(1), 16 -25.

Zámbó, L. (2001) A mikrobiális talajhatás morfológiai jelentősége a karsztosodásban. Földrajzi konfer-encia, Szeged.

Zámbó, L. & Telbisz, T. (2000). A mikrobiális be-folyásoltságú karsztkorró- zió vizsgálata magyar-országi karsztok talajaiból származó kismintá-kon. Karsztfejlődés, V, 21-39. BDF, Természet-földrajzi Tanszék, Szombathely.

Zámbó,L., & Ford, D. (2003). Corrosional factors of the epikarst. In:Horváth,G.(ed.), Soil Effecton Karst Processes (pp. 7–18). Budapest.

Zhang, M. & Zhang, F. (1987). Soils under karst forest in Maolan. Collection of Maolan karst science ex-plore. Guizhou Science Express, 111-124.

Williams, P. W. (1983). The role of the subcutaneous zone in karst hydrology. Journal of Hydrology, 61(1-3), 45-67. doi:10.1016/0022-1694(83)90234-2

Williams, P. W. (2008). The role of the epikarst in karst and cave hydrogeology: a review. International Journal of Speleology, 37, 1-10. Retrieved May 13, 2018, from http://scholarcommons.usf.edu/cgi/viewcontent.cgi?article=1173&context=ijs.

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Arch dam failure preliminary analysis using HEC-RAS and HEC-GEO RAS modeling. Case study Someșul Rece 1 reservoir

Daniel SABĂU[1,*], Gheorghe ŞERBAN[2]

[1] Romanian Waters National Administration - Someş-Tisa Water Branch, 7 Vânătorului Street, 400213, Cluj-Napoca, Romania
[2] Babeş-Bolyai University, Faculty of Geography, 5-7 Clinicilor Street, 400001, Cluj-Napoca, Romania

* *Corresponding author*: andrei.sabau@dast.rowater.ro

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Abstract

This paper presents a preliminary analysis/simulation of the Someşul Rece 1 dam breaking scenario, from the homonym hydrographic basin, located in the north-eastern part of the Apuseni Mountains, at a 0.1 % probability tributary flow rate calculation. The study of the floodplain areas, that occur after the failure of the Someşul Rece 1 dam, was achieved with the help of 1D hydrological modelling. This type of modelling is one of the most complex (Cameron et al., 2006), involving both, the definition of a model with temporal evolution of the dam rupture, and the simulation of a unsteady flow stream in the downstream sector. For the dam analysed area and the downstream sector, several scenarios and modelling of hydrological systems was achieved, with the help of HEC-RAS 5.0.3 software, developed by the Hydrologic Engineering Center (U.S. Army Corps of Engineers).
This free software is the most widely used worldwide in the domain, particularly by the official agencies, having a continuous development, given by the involvement of specialists. The software simplifies the problem of hydrodynamic modelling, due to the limitation to a 1D model. Because the flood obviously has a spatial character, GIS software (ESRI ArcGis with the HEC-GeoRAS extension) were used in determining and defining the hydrographic elements (channel, talweg, banks etc.) and, also, in the representation of the results. Maps of the flood-prone areas have been developed, maps which indicated the magnitude of the estimated accidental flood downstream. The results of the simulation were also used to determine the anticipation time.

Keywords: *dam break, breach, HEC-RAS, Someșul Rece, hydrograph*

Rezumat. O analiză preliminară a scenariului de rupere a barajului în arc folosind modelarea HEC-RAS și HEC-GEO RAS. Studiu de caz barajul Someșul Rece 1

Această lucrare prezintă o analiză/simulare preliminară a scenariului de rupere a barajului Someșul Rece 1, din bazinul omonim, situat în nord-estul Munților Apuseni, la un debit de calcul afluent cu probabilitate de 0.1 %. Studiul arealelor inundabile, care apar după ruperea barajului Someșul Rece 1, s-a realizat cu ajutorul modelării hidrologice 1D. Acest tip de modelare este unul dintre cele mai complexe (Cameron et al., 2006), implicând atât definirea unui model cu evoluție temporală a rupturii barajului, cât și simularea unui flux inconstant de scurgere în aval. Pentru zona barajului analizat și sectorul din aval am realizat mai multe scenarii și modelări ale sistemelor hidrologice, cu ajutorul softului HEC-RAS 5.0.3 dezvoltat de către Hydrologic Engineering Center (US Army Corps of Engineers).
Acest soft gratuit este cel mai utilizat din domeniu la nivel mondial, îndeosebi de către agenții oficiale, având o continuă dezvoltare, dată de implicarea specialiștilor în domeniu. Softul simplifică problema modelării hidrodinamice, datorită limitării la un model 1D. Pentru că inundația are evident un caracter spațial, softuri GIS (ESRI ArcGis împreună cu extensia HEC-GeoRAS) au fost utilizate, atât în determinarea și definirea elementelor hidrografice (canal, talveg, maluri etc.) cât și în reprezentarea rezultatelor. Au fost elaborate hărți ale arealelor inundabile, care au indicat amploarea estimată a inundațiilor accidentale în aval. Rezultatele simulării au fost utilizate și pentru a determina timpul de anticipare.

Cuvinte-cheie: *ruperea barajului, breșă, HEC-RAS, Someșul Rece, hidrograf*

Introduction

Dams have a vital role in water resources management. In addition to their beneficial role (multiple uses), dams can be, also, the source of any catastrophic accidents. Although rare, such events are of the most extreme, due to the human lives loss and huge damage caused.

Failure of a dam is defined as the breaking or displacement of a part of the dam body or his foundation, resulting that the dam cannot retain water. This leads to uncontrolled release of a large volume of water, from the reservoir, in a very short time.

When downstream of a dam there are socio-economic objectives, it is extremely important to determine through the high-precision hydrodynamic modelling, the fracture hydrograph and the propagation time, in relation with the starting time of the dam breach formation. These are very important, to provide a maximal anticipation time of forces involved in the efforts to evacuate people and property (Stematiu and Ionescu, 1999).

At the international level, the dam safety has always been in the centre of the ICOLD (International Commission on Large Dams) attention, and the ultimate goal of the taken actions was to reduce the number of disposals and incidents. The failure of a dam may cause "material damage exceeding dozens of times the cost of the construction and many human victims" (Popovici, 2012). The progress made in the design conceptions and construction technologies, in the supervision of the dam behaviour during it exploitation, has led steadily in time to the "rate of incidents or dam disposals decrease" (Roșu and Creţu, 1998).

In the literature, it is noted that the rate of dam disposals, before the year of 1900, exceeded 4%, while in the present this rate stands at less than 0.5%. Moreover, the percentage of dam disposals in the world has decreased to 2.20% in the case of dams built before 1951, to less than 0.5% in the case of the dams built after 1951 (ICOLD, 1995).

The compiled statistics classify, from many points of view, the main causes of these breakdowns. Here, the disposal of the foundation, the limited capacity of the spillways and lesser, the insufficient mechanical strength, have the largest share (Drobot et al., 2007).

In Romania such cases have been, also, recorded, examples being the failure of the Belci dam (June 1991), the damage produced to the Teleag improvement, on the Crişul Repede river (February 1992) or the cracking of the Cornățești – Olt dam (April 1997), with a central crack of 2...3 m.

The conclusion that emerges is that although we are, overall, below the world average of the damages, one can make a similarity with their casuistry. This favours the development and application of theoretical and experimental investigations for the improvements in our country (Popovici, 2012).

At the end of the XXth century and the beginning of the XXIth century, the publication of data related to damage and breaking of several dams in Romania, favoured the starting of the pioneering studies in this domain.

The legislative regulations in the last five years have required to holders of important dams to draw up the "Plans of action in case of accidents at dams". These plans are periodically updated to agree both with the new legislative regulations and with any changes resulted from the construction or in its exploitation rules.

"Plans of action in case of accidents at dams" shall be developed in accordance with the Order of the Ministry of Environment and Forests/Ministry of Administration and Internal Affairs (MEF/MAI) 1422/192/2012, order on the management of emergency situations rules. These plans respect the purviews of the Government Decision G.D. no 646/2010 for the approval of the National Strategy for the Management of Flood Risk and the Analysis and assessment of the risk associated with the dam normative framework NP 132 of 2011.

Therefore, in last years the "Romanian Waters" National Administration (RWNA) has conducted the studies regarding the water management on floods produced by the damage and breakage of the dams (A and B categories) under its own administration.

In the Upper Someşul Mic hydrotechnical system, there are six dams of A and B importance category, where only the Gilău dam is in the administration of the ”Romanian Waters” Administration and has drawn up an action plan in case of an dam accident.

The analysis of the dam breakage includes a detailed study on the causes of the dam failure, on the technical parameters and on the generated floods wave, with its impact on the downstream objectives.

The study area and general information related to the studied dam

Someşul Rece river (Fig. 1) forms, by the union with Someşul Cald river in Gilău lake, the Someşul Mic river. This first water course has a length of 49 km, it springs from the Muntele Mare massif through the Zboru creek at 1560 m altitude, on the territory of the Cluj county.

Its drainage basin, positioned between the basins of Someșul Cald and Iara rivers, overlaps to a great extent following the Muntele Mare and Gilău massives, in the north east of the Apuseni Mountains. The drained surface is 327 km2 with an average altitude of 1214 m (Atlas Cadastre of Romanian Waters, 1992).

The natural conditions in the upper basin of Someşul Mic river, favoured a large-scale hydrotechnical improvement, which capitalized a part of the existing natural potential in this area (Fig. 1). The 860 km2, area of the basin in the section of the Gilău dam, were the subject of the spatial planning since the end of the '60s. In this regard, were built four great dams with reservoirs on the valley of the Someşul Cald river (Fântânele, Tarniţa, Someşul Cald and Gilău). Also, several intakes and adductions intended for supplementing the tributary flow into these four lakes were built in the drainage basin of Someşul Rece river (Serban, 2007).

The improvement was extended beyond the watershed, which separates the Someșul Mic and the Arieş basins, by achieving more intakes and adductions in the upper basin of the Iara river, whose water was also directed on the reservoirs from the Someșul Cald river (Fig. 2).

In the first stage of improvement (1968-1980 years) have been realised the largest reservoirs from the basin. Gilău was the first reservoir given in service, in 1972, followed by Tarniţa, in 1973 and Fântânele, in 1976.

Also during the first stage have started the works on the intakes and the derivations from the basins of Iara and Someşul Rece, some of these being given in service (Someşul Rece II system).

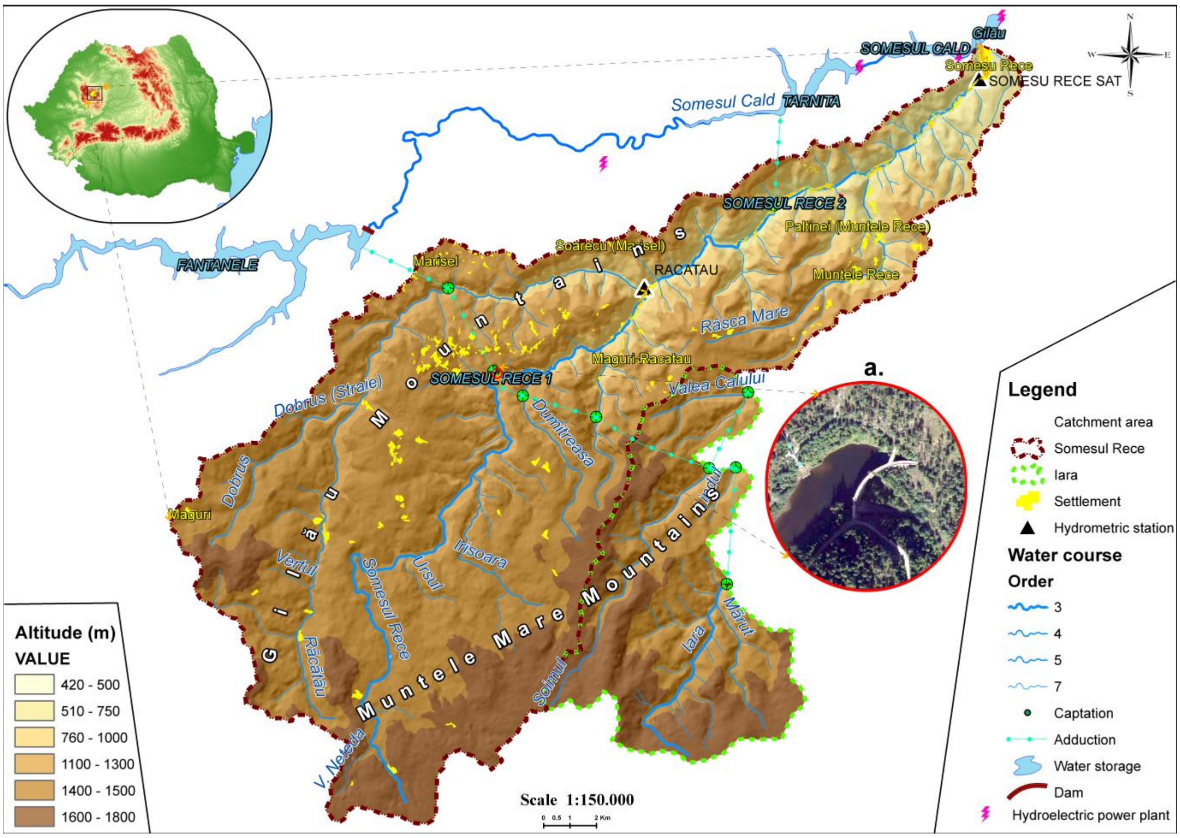

Fig. 1: The location of the study area in relation with national territory and Someşul Mic upper basin hydropower improvement

In the second stage (1980-1990) the Someșul Cald river improvement was done, by the given in service of homonymous reservoir (1983).

The main axis of the secondary improvements is Iara-Fântânele. Its adduction has a total length of 21 km, of which: 4.7 km between the intakes Iara and Șoimu, 4,9 km between the intakes Șoimu ans Negruța, 4 km between Negruța intake and Someşul Rece 1 reservoir, 3.7 km between Someşul Rece 1 reservoir and Răcătău intake, and the same length between Răcătău intake and Fântânele reservoir (Pop, 1996).

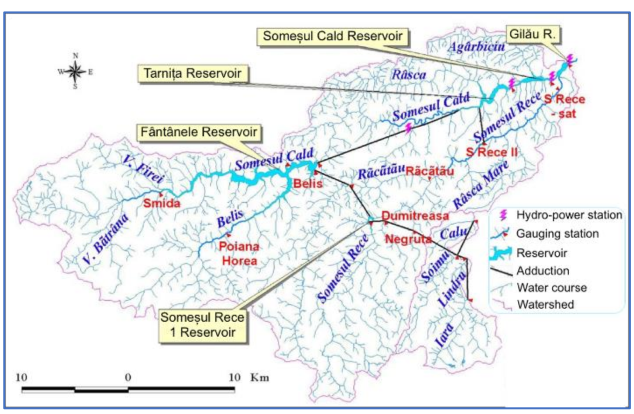

Fig. 2: The Someşul Mic upper basin hydro-power improvement

The time elapsed in the post-improvement period, proven that the adductions and the intakes does not represents a protection against the flash floods, for the settlements located downstream. Those 4,89 m^3/s, captured on average in the basin of Someşul Rece river, and even the maximum of 27.8 m^3/s, cannot significantly reduce the threat of flooding, in case of flash floods with a maximum discharge whose probability of exceedance is below 10% (Şerban et al., 2009).

Someşul Rece 1 Dam

Someşul Rece 1 Dam (Fig. 1a) is located in Cluj county on the homonymous river, upstream of the confluence with Dumitreasa river, of the Măguri-Racătău locality and about 40 km upstream of Cluj-Napoca municipality. The dam is under the administration of S.C. Hidroelectrica S.A. - Cluj Hydropower Station Branch.

The construction is an arch with a double curvature, being one of the largest dams with secondary role in a complex hydropower improvement in Romania. Its dimensional parameters are: 43.5 m height, a length at the crest of 119.5 m (altitude of the crest 1024.5 m-Black Sea) and include a concrete volume of 50,000 m3 (Regulation of the

Fântânele Reservoir Exploitation, 2010, ”Someș-Tisa” Water Basin Administration).

The Someşul Rece Dam is located in the gorge sector of the Someşul Rece river, with its both slopes steep and a general symmetry of the valley. The foundation of the dam is composed from volcanic rocks strong and healthy, respectively granite by Muntele Mare Mountains.

During the dam construction and exploitation has not been signaled any kind of dangerous geological phenomenon. The dam is composed from 14 consoles, where 2 of these forms the high waters spillway, organized laterally.

The dam represents the first and most important step of the Someşul Rece river improvement, otherwise the only intake with storage, followed downstream by the Someşul Rece II intake. The given in service of the Someșul Rece 1 dam (1977) is subsequent to the Fântânele dam (1976).

The Someşul Rece reservoir

The Someşul Rece 1 reservoir plays the role of a simple intake with tyrolean outlet, but which, from the needs dictated by the quotas game, it was necessary to accumulate a minimum of 0.2 million m3 of water, for the hydraulic agent to be conducted by gravity into the Fântânele reservoir.

The main functions of the Someşul Rece 1 reservoir are:

- supplementing the tributary flow in the Fântânele reservoir, for the production of electricity by hydropower plants located downstream on the Someşul Cald river;
- partial attenuation of flood waves;
- recreational.

Flood mitigation is insignificant due to the extremely reduced dedicated volume, as this function has not been designed for the Someşul Rece 1 reservoir. However, it can hold a volume of 0.74 million. m3 between the 981,00 m-BS and 1020,5 m-BS (the last value is Normal Retention Level) and a volume of 0.26 million. m3 between 1020,5 m-BS and 1024,00 m-BS (Maximal Retention Level), the rest of the flow being transited through the adduction outlet, respectively through the bottom and high waters outlets.

Materials and Methods

The database used in the analysis consists in both technical as well as hydrological data, collected from the Archive of the ”Someș-Tisa” Water Basin Administration, Cluj-Napoca.

For the mapping, have been used topographic maps at scale of 1:25000 and GIS software licensed from the two institutions involved in this study: Babeş-Bolyai University, Cluj-Napoca, Faculty of Geography and ”Someș-Tisa” Water Basin Administration, Cluj-Napoca.

Basic data necessary for the HEC-RAS hydrodynamic model

The study, consisting in the analysis of the values of maximum flows in influenced regime (IR) and in natural regime (NR), with different probabilities of exceedance, as well as the characteristic elements of the singular flash flood waves type, for the main cross-sections on Someş Rece river, was made based on data and the conclusions drawn by the specialists from ”Someș-Tisa” Water Basin Administration departments.

The data on the type hydrograph tributary in the reservoir were processed with the CAVIS software, and the cartographic representation were realised using ArcMap 10.x software.

In the analysis, were used topographic data, representing the basis of the hydraulic calculus, regarding the simulation of production and propagation of the breaking wave downstream of the Someşul Rece 1 dam. These data consist in theNumerical Model of Terrain (NMT), cross profiles and surveys at bridges on the Someşul Rece river (Fig. 3). *These topographic data have been obtained within the project ”Plan for the Prevention, Protection and Mitigation of Floods Effects in Somes-Tisa River basin”*, a national project financed through ”AXA 5 POS Mediu”.

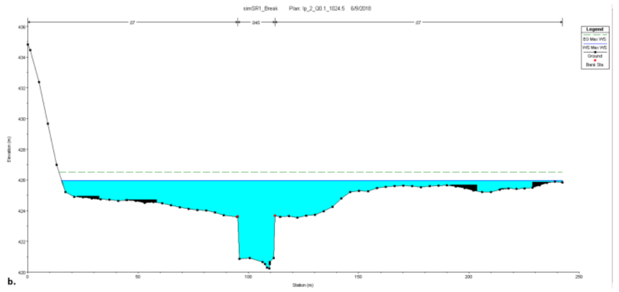

Fig. 3: Example of surveying (a) and cross section (b), entered and processed in HEC-RAS. Source of raw data: PPPDI-STWBA

In this study, the analysis of the dam rupture and the modelling of the induced floods was performed using HEC-RAS. The Hydraulic Engineering Center - River Analysis System (HEC-RAS) is developed by the Hydrological Engineering Center of the U.S. Army Corps of Engineers (USACE).

The HEC-RAS model simulates the flow in the fluvial channels and in flood prone areas, being considered an effective model in simulating the effects of floods downstream of the location of an event occurrence, in this case the failure of the dam. The HEC-RAS model uses the failure information and the breaking geometry as input data to simulate the pattern of dam failure.

Cameron et. al., in the paper ”Dam failure analysis using HEC-RAS and HEC-GeoRAS”, published in 2006 in the ”Third Federal Interagency Hydrologic Modeling Conference” conference proceedings, considers that a rivers hydraulics model will be as good as the data and personnel used to develop it.

Detailed information on the riverbed and flood prone areas are the main data required to create a hydraulic model of a river. Data on the land use (used for the estimation of the Manning roughness coefficients) and information on the hydraulic engineering structures (bridges, footbridges, dikes, supporting walls etc.), are also essential for the construction of a complete fluvial hydraulic model. Therefore, the topography plays a major role in the accurate determination of areas vulnerable to accidental flooding, and for this determination it is necessary a fair resolution of the topographic surface, in the form of NMT (Numerical Model of the Terrain) (Serban et al., 2016).

In this analysis, we considered only the hydrographic elements of interest. For example, the tributaries have not been defined anymore, because their contribution as flow is not significant in the context of severe flooding values generated by the failure of the dam. In order, not to complicate the modeling, these rivers have not been added, keeping, however, a way to achive the profiles, which consider these confluences and the altitudinal expansion on upstream. Figure 4 illustrates the manner in which study sector was define.

Fig. 4: Image of the downstream sector of the Someşul Rece 1 Dam exposed to flooding in case it failure, modeled with HEC-GeoRAS

In the study was used the the numerical model of the land with a spatial resolution of 3 meters, realized within the PPPDI project. In order to extract the values of the Manning coefficient, have been use Corine Land Cover 2012 data. Also, all constructions (houses, annexes, buildings) situated in the flooding area have been digitized in advance, constructions that can have an obstruction role in the path of the stream. Taking into account the significant potential of flooding, the study sector was extended downstream of the dam position, up to the confluence between Someşul Rece and Someşul Cald rivers, in Gilău reservoir.

The Someșul Rece valley on the previously mentioned sector, with a length of 29 km (Fig. 5b), has been configured in the model, through cross sections topographically determined at equidistances. In addition to the mentioned sections, other cross-sections were interpolated in the HEC-RAS program between the original cross-sections (Fig. 5a).

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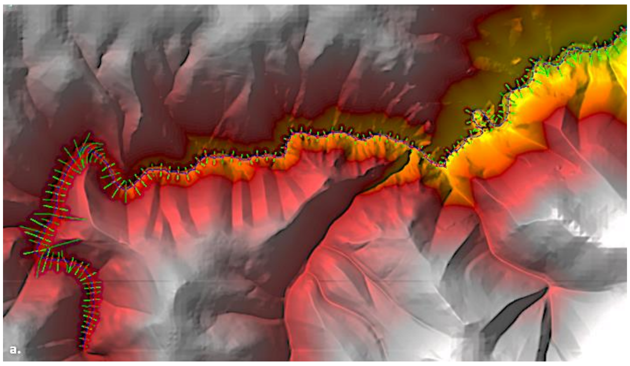


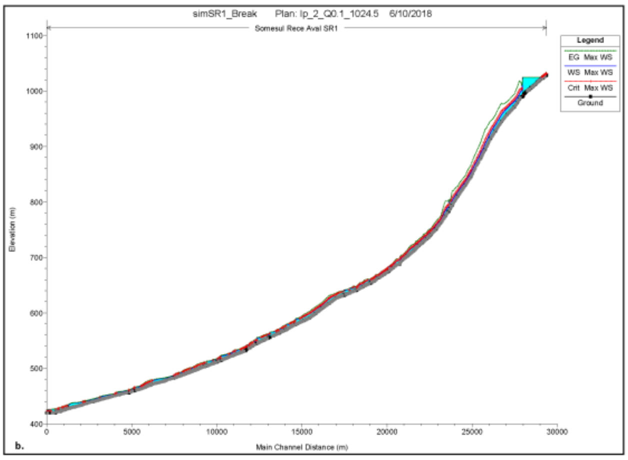


Fig. 5: The three-dimensional model of the terrain and the cross-sections arrangement (a.), longitudinal profile downstream of the dam sector (b.)

Taking into account the Manning coefficient of roughness for the minor riverbed and floodplain, have been used values between 0,045 and 0,09, depending on the particularities of the section. Loss of the hydraulic load related to the expansion and contraction of the riverbed or to natural obstacles, is included in the model with coefficients between 0.3 and 0.1.

HEC-RAS software is based on solving the Saint-Venant fundamental equations, the equation of continuity and moment.

$$\frac{\partial AT}{\partial t} + \frac{\partial Q}{\partial x} - qI = 0$$

$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + Sf\right) = 0$$

where: z = elevation of water surface, m; AT = total flow area, m2; Q = flow, m3·s–1; qI = lateral inflow per unit length, m2·s–1; Sf = friction slope; V = flow velocity, m·s–1.

Equations with partial derivatives (Barkau, 1982), are the basis of the unstable flow calculus solution in the HEC-RAS. The numerical solution of these equations is given by the use of differential finite method (Bruner, 2008).

Topographic Data

In the modeling topographic data are necessary, data which characterize the whole potentially flooding area. The size of these data should not be underestimated. The floods resulting from the dam breaching can be significantly higher than natural flooding. Thus, the topographic surface needed to be modeled extends on flood plains and slopes, above the normal levels of flooding. Details regarding the major structures which can form an obstruction of flow are, also, required, such as bridges, footbridges, roads backfill, civil bordering constructions and the most important river control structures.

The precision of a simulation study on the dam breakage is different from that of the watercourses modelling study, whereas the latter simulates the natural flooding, which occur in areas defined as floodable areas. Knowledge of the flow typical conditions and of the modeling parameters, such as the roughness of the channel and the flooded floodplain for these events, is relatively good. For a dam breaking model, flow conditions consistently exceed the usual natural events. This means that there are few calibration data, and the flooded land is outside of normal floodplain, which makes it difficult to estimate the roughness and other parameters of input.

Flow Data

Boundary conditions for the calculations are necessary. In a subcritical runoff analysis, the boundary conditions are only required at the downstream limit of the river system. In a supercritical flow analysis, the boundary conditions are required only at the upstream limit of the river system. In a mixt flow regime boundary conditions at the open limits of the river system will be provided.

Routing the inflow data throught a Reservoir

HEC-RAS can be used to route an inflowing hydrograph throught a reservoir with any of the following three methods (US Army Corps of Engineers, 2014):

- one-dimensional unsteady flow routing (full Saint Venant equations);
- two-dimensional unsteady flow routing (full Saint Venant equations or Diffusions wave ecuations);
- level pool routing.

Generally, full unsteady flow routing (one-or two-dimensional) will be more accurate for both the with and without breach scenarios. The unsteady flow routing method can capture the water surface slope through the pool as the inflowing hydrograph arrives, as well as the change in water surface slope that occurs during a breach of the dam (US Army Corps of Engineers, 2014).

In this study, we use the most accurate methodology - full dynamic wave (one-dimensional unsteady flow routing - full Saint Venant equations). To model the reservoir using full dynamic wave routing with HEC-RAS, we model the pool with one-dimensional cross sections throughout the entire reservoir.

Catchment Hydrology

Tributary hydrograph, reservoir status at the time of the dam breaking and the downstream base flow conditions can be combined, to have a significant effect on the predicted flooding scenario, depending on the size and nature of the reservoir and of the dam.

Boundary Conditions

In this analysis, the limit condition provided in the upstream, is the tributary hydrograph calculation type with the assurance of 0.1%, and the downstream limit condition is the normal depth. This option uses Manning's equation to estimate a level for each calculated flow. To follow this method, the user must enter a friction slope in the vicinity of the downstream limit condition.

The lymnimetric key is another option, that is used as a downstream condition limit. The tributary hydrograph of laterally side input is used as an internal limit. This option allows the user to bring the tributary contribution in a certain point along the river.

Scenario of the dam-break

Constructed dams can be categorized in two large groups: gravity and arch dams (Fig. 6). Gravity dams rely on their weight to resist the forces imposed upon them. Arch dams, with the arch pointing back into the water, use abutment reaction forces to resist the water pressure force. They can be made of concrete or masonry.

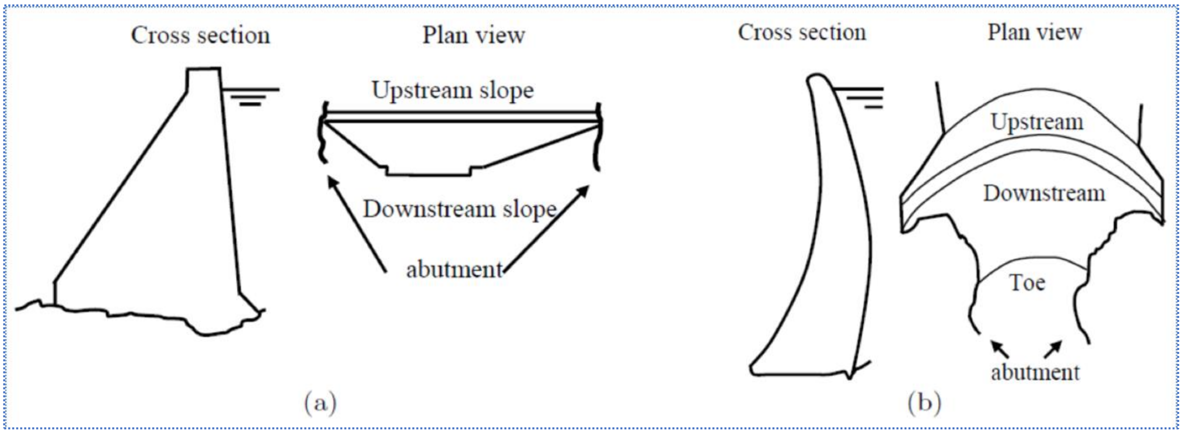


Fig. 6: Schematic picture of (a) gravity and (b) arch dams

The failure of a structure can be partial or complete. Failure of a dam can be sudden or gradual. A sudden failure is associated with concrete dams, gravity or arch dams. The Malpasset Dam in southern France, an arch dam of 66.5 m in height and maximum designed reservoir capacity of 55 million m3, is described to have failed explosively on 2 December 1959, water storage was emptying in about an hour (Hervouet, 2000).

If breaching is initiated, the further development is faster than for earthfill dams under the same conditions. This observation allows modelling of the concrete arch dam failure events simply as a sudden (gate opening) process (Zagonjolli, 2007).

This approach, though appropriate for concrete and arch dams that usually exhibit a failure within a relatively short duration of time - similar to sudden failure - did not provide insight into the breach modelling processes except for the flood wave movement in the downstream channel (Dressler, 1954). A thin plate representing the dam was located in a rectangular 'channel', and its removal simulated instantaneous failure of the dam.

The shape of the hydrograph breaking at the peak flow is influenced by the level and volume of water in the reservoir at the time of the breach, by the size of the dam and, most importantly, by the vulnerability to erosion of the dam type and by the assumed scenario for breakage. For example, a concrete fragile structure will have a much faster development of the breach compared to a weight dam built from local materials, cohesives, well compacted and well stabilized by vegetation. Because the hydrograph of the flow can greatly vary depending on these factors, it is necessary to conduct a careful analysis of the dam breaking parameters.

For the concrete dams, especially at the arch dams or with abutments, the total breaking takes place in a very short time, of a few minutes. The flow rates in the riverbed exceed the flow rates of the natural catastrophic flood. The features of the rupture hydrograph and of the flood wave, depends on the height of the dam, the volume of the reservoir, the breaking model of the dam and the hydraulic characteristics of the riverbed downstream. For the arch or multiple arch dams , it is considered that the duration of the damage is very short, about seconds, in the calculation taking frequently and coating the instant destruction, though practically volatilization of dams is impossible.

In this study, we have considered the discharge over the crest (overtopping) as the main cause of the breakage of the dam, caused by the tributary runoff hydrograph with 0.1% insurance, correlated with the partial blockage of the high waters discharger.

For the failure scenario of the arch dam with double curvature, there were used the standards of the United States Army Corps of Engineers (USACE), indicated in the guide to Using HEC-RAS For Dam Break Studies, HEC 2014 (Table 1).

Table 1. Concrete arch dam breach characteristics (source USACE, 2014)

Failure mode	Dam Type	Over-flow/Weir Coefficients	Average Breach Width	Horizontal Component of Breach Side Slope (H) (H:V)	Failure Time, tf (hours)
Overtopping	Concrete Munti-Arch	3.1	(0.8xL) to L	Valley wall slope	≤0.1

In this analysis, for the breaking scenario of the Someşul Rece 1 dam, we believe that the breach will form in 6 minutes, representing the rapid and almost complete disposal of the arch dam (Fig. 7). In this scenario, the dischargers of the dam will be adapted in accordance with the rules of construction exploitation at high waters. In Figure 7 is shown both the shape and time of the breach formation.

To assess the behavior of the model, an input hydrograph is necessary to show the variations of discharges for a certain period of time. A calculated type tributary hydrograph with the 0.1% assurance was imported in the model. The simulation was made for an unstable flow-regime of 45 hours duration.

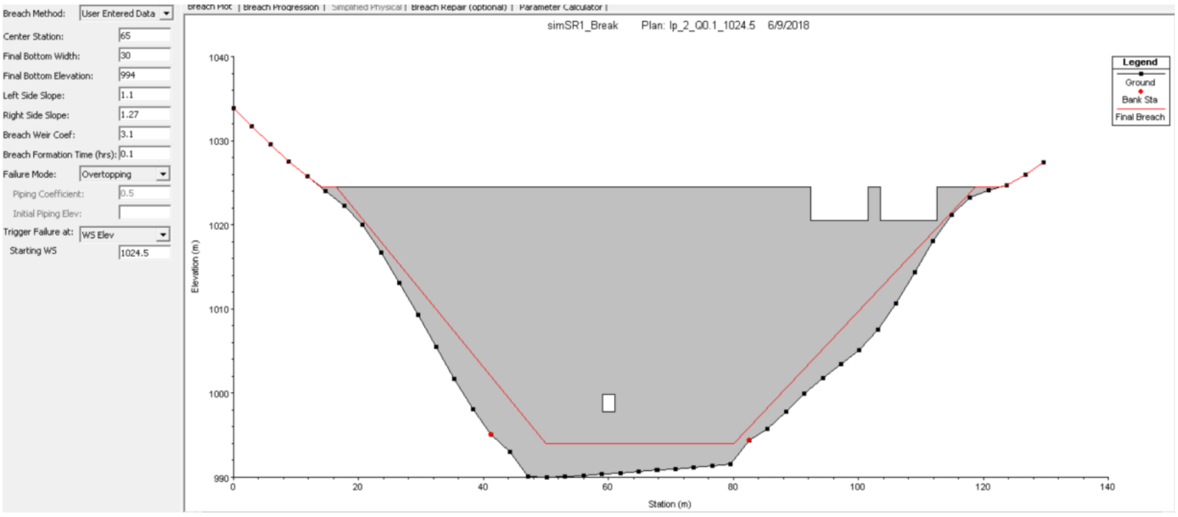


Fig. 7: The shape of breach

Results

After setting the parameters and complete the calibration in the control section of the Someşul Rece hydrometric station, the model determined the level of the free water surface and the flow hydrographs, using a two minutes calculation interval, which generates a very accurate hydrograph. A shorter period would generate an even more accurate hydrograph, but also a very large amount of data, while a longer interval of time would produce a less accurate hydrograph.

The flow passes through critical velocity to the downward slope, in this case the characteristics of the breaking wave including: the maximum level, the debit, the variations of water level in the reservoir up to the dam failure, the average velocity on the section (Fig. 8).

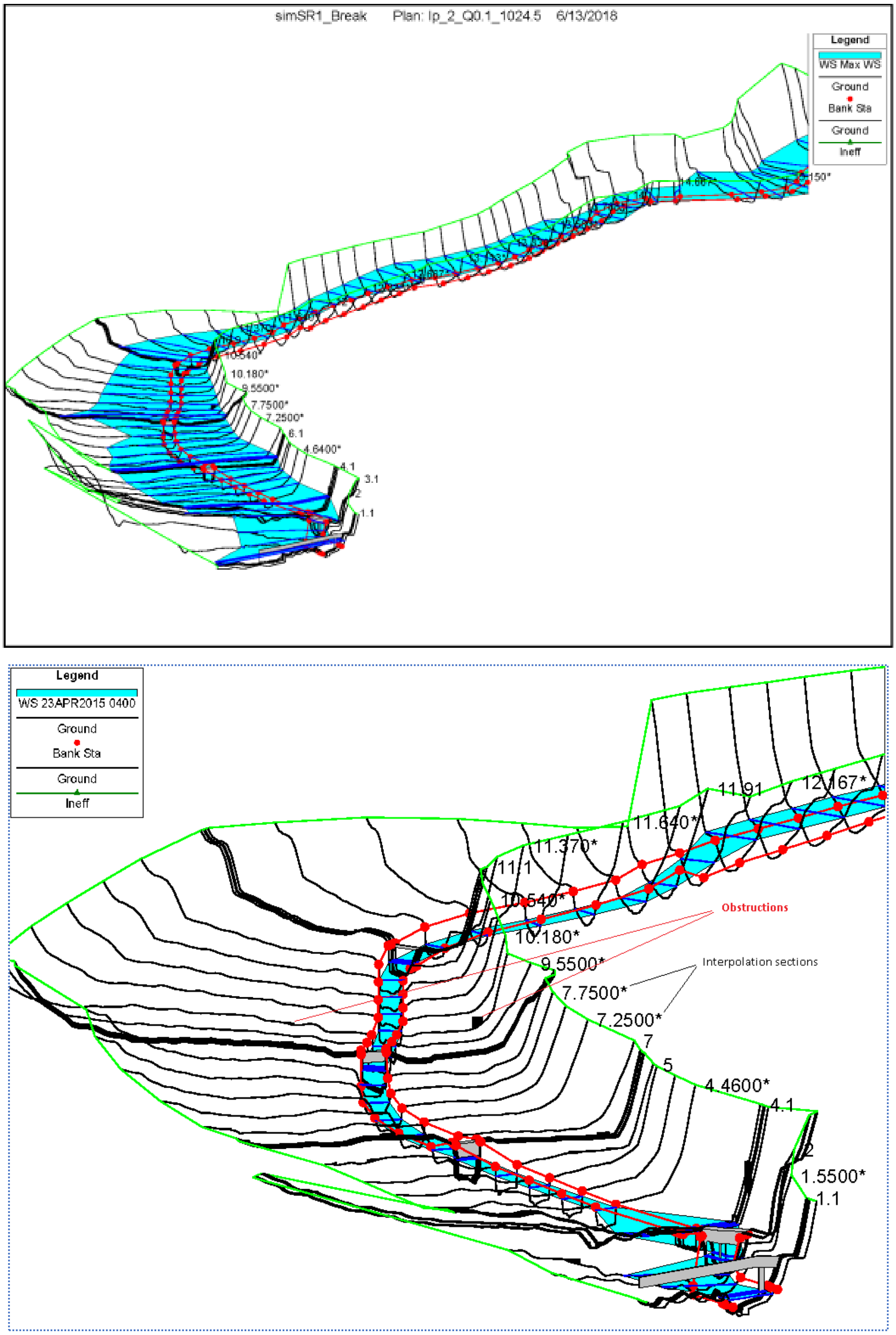
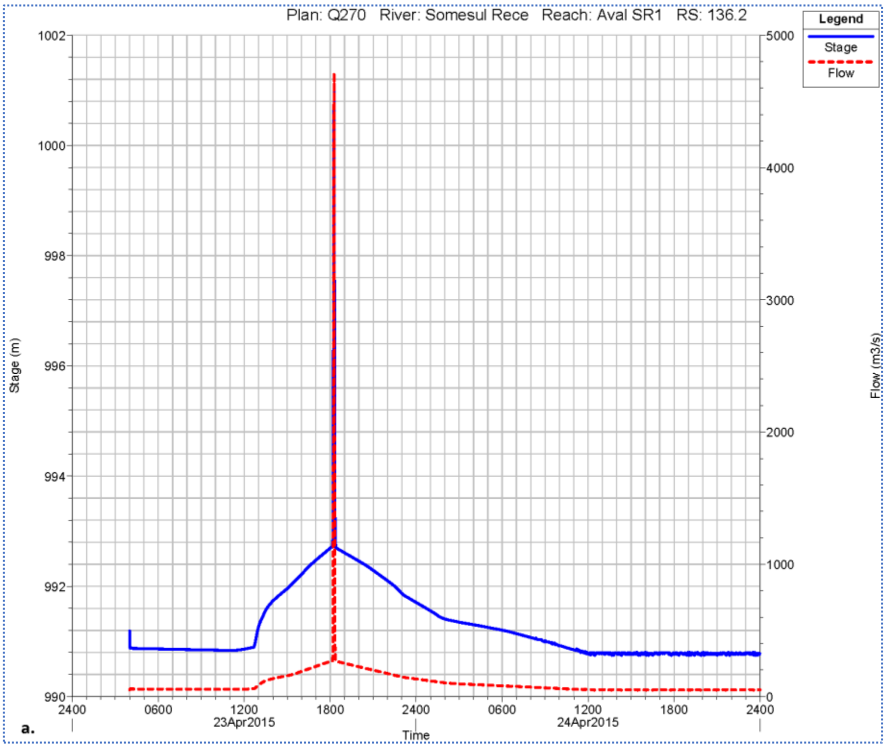


Fig. 8: 3D multiple cross section plot for the most important settlement (Someşul Rece village) traversed by the river

Features of the hydrograph of the Someşul Rece 1 dam breaking

The rupture hydrographs shall be determined by assimilating the drainage of water from the lake with a flow over a spillway with a sill wide, whose task and sizes are reevalued at the successive calculation times. These hydrographs are characterized by a shorter period of the time increase, as forthe total time (minutes) as compared to those for the natural hydrographs.

Also, values of accidental maximum flows much higher than that of natural maximum flow are characteristic, in our case 17 times higher than the flow rate with the 0.1% assurance, (Fig. 9 a and b).



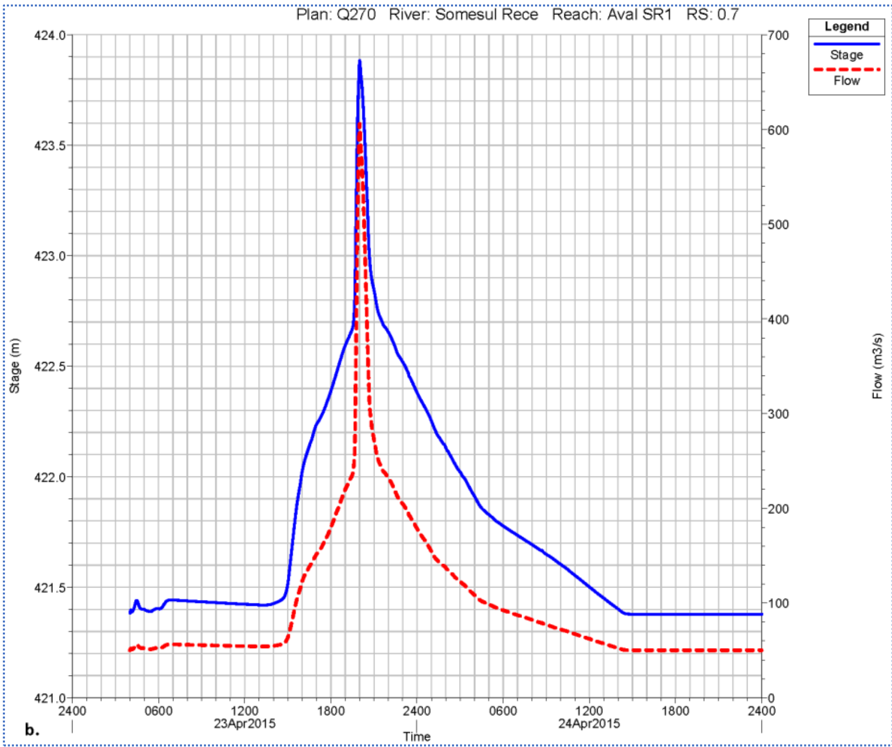


Fig. 9: Levels and flows hydrographs - a. Section immediately downstream of the dam; b. The last section from the Gilău lake entrance

In our case scenario, the breaking wave flow comprises, also, the tributary flash-flood flow into the lake, because the breach is formed as a result of the discharge over the canopy of the dam.

The Someşul Rece river narrow corridor, downstream of the homonym reservoir, has a gorge like aspect, with numerous narrowing and widening areas of the valley. This aspect, alongside with the roughness elements of the major riverbed, makes the amplitude of the generated flash-flood peak to be considerably reduced, along these 29 kilometers, from 4450 m3/s, registered immediately downstream of the dam, up to 555 m3/s at the entrance in the Gilău reservoir. Although the attenuation is more than consistent, the water height at the maximum level of the flashflood is sufficient to inundate nearly half of the Someşul Rece- village and generate significant damages (Fig. 10).

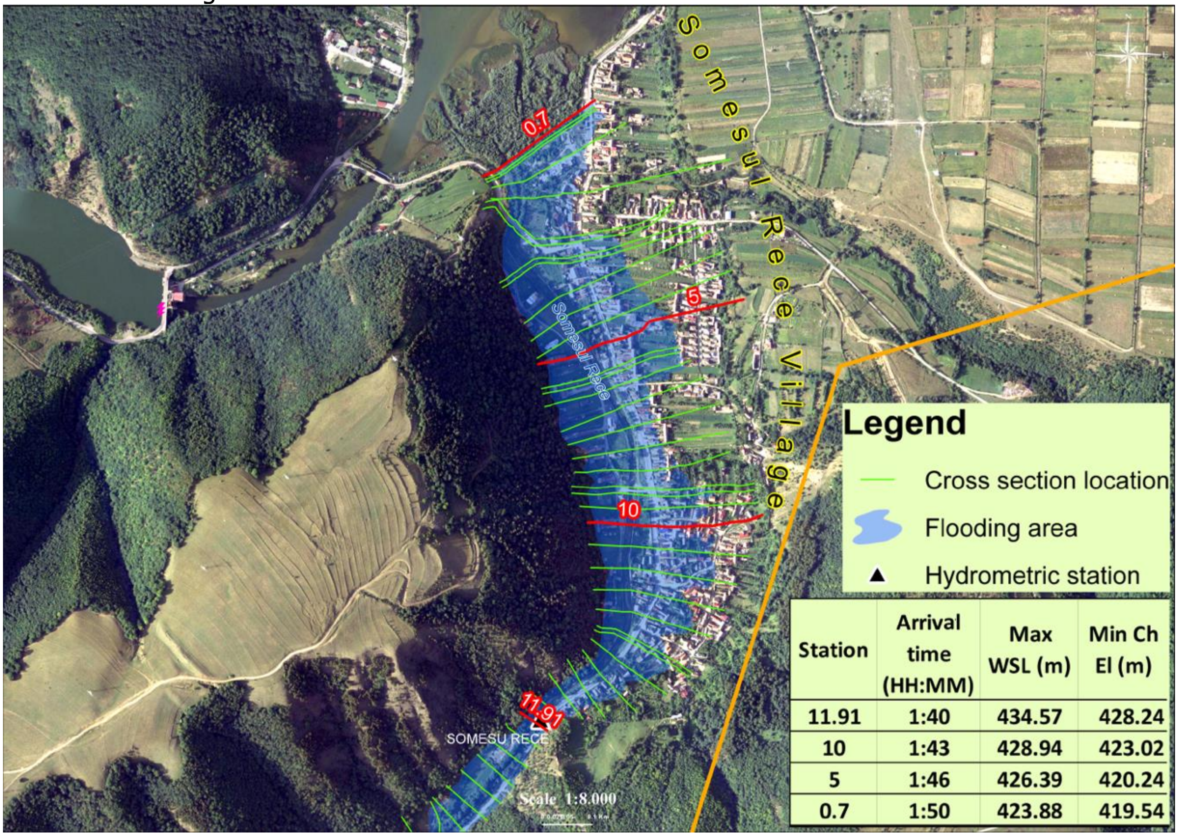


Fig. 10: Flooding map for Somesul Rece Village

Flooded area

The resulting flooding map, offers informations about the areas with flooding risk , the accidental wave with a rapid acceleration and the turbulent supercritical flow, which propagates in the downstream area (Fig. 10). On the gorge sectors, the level of energy increases significantly with the propagation of the wave through the narrow and steeper valleys. A vulnerability map was drawn up for Someşul Rece village to make people aware about the risks of flooding. It includes the area exposed to the flood and the time of anticipation, which can be effective in reducing the damage caused by the flood and reduce the number of victims.

For our scenario, the propagation time of the dam breaking wave is 1.5 hours up to the confluence with the Gilău lake, a sector of 29 km in length.

Conclusion

This paper highlights the high risk of exposure for the socio-economic objectives located downstream of the Someşul Rece 1 dam, in case of dam failure. In the mountain area, the spatial typology of the villages, located along the watercourse, determines a high risk for the population in case of a dam break. The results revealed by the modeling in the HEC-RAS, have shown that the accidentally wave arrive in the first village (Măguri Răcătău) in a few minutes (18 min), with a flow rate of 2061 m3/s, and spreads very quickly downstream. The good synchronization between the wave arrival time and the peak debit (or the maximum water depth with no appreciable distinction) indicate that the water profile poses a very steep front, which is typical for accidental waves, which propagate through the riverbeds with a big slope.

The identification of flooded areas, of the flooding depth, of the water velocity and the of the flood duration, as well as the impact of the flood on the affected areas, are very important for decision-making, emergency evacuation and early warning. This study is also important when designingthe high waters spillway capacity, in particular for the arch dam. The importance of implementing an alarm sirens system should not be neglected, in case of failure of the dam. The Someşul Rece 1 dam failure might even endanger the objectives located at a further distance, i.e. up to the entrance of the homonym river in Gilău lake.

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References

Cameron, T., Ackerman, C., Brunner, G.W. (2006) Dam failure analysis using HEC-RAS and HEC-GeoRAS. Proceedings of the Third Federal Interagency Hydrologic Modeling Conference, April 2–6, Reno, Nevada, USA, 8 p.

Barkau, R.L. (1982) Simulation of the July flood along the Salt River. Report for CE695Bv. Special Problems in Hydraulics. Collins, CO. Colorado State University. Department of Civil Engineering pp. 231.

Bruner, G.W. (2008) HEC RAS_4 River Analysis System Reference manual. Version 4. pp.46

Dressler, R. F. (1954) Comparison of theories and experiments for the hydraulic dam-break wave, Vol. 3, Proc. of the International Association of Scientific Hydrology, Rome, Italy, pp. 319–328.

Drobot, R., Amaftisei, R., Alexandrescu, M.-I., Cheversan, B. (2007) Modelarea efectului unui scenariu de cedare a barajului Lacul Morii (Modeling of the Morii Lake dam failure scenario effect - in Romanian), Hidrotehnica, vol. 52, nr. 12, p. 8-14.

Hervouet, J.M. (2000) A high resolution 2-D dam-break model using parallelization, Hydrological Processes 14(13), 2211–2230.

Pop P. Gr. (1996) România - Geografie hidroenergetică (Romania - Hydropower Geography - in Romanian). Editura Presa Universitară Clujeană, Cluj-Napoca, 237 p.

Popovici, A. (2012) Consideraţii asupra temei Q93 de la Congresul al XXIV – lea al Marilor Baraje (Considerations on the Q93 theme from the XXIVth Congress of the Large Dams - in Romanian), Kyoto, UTCB.

Roșu, C., Crețu, Gh. (1998) Inundații accidentale (Accidental flooding - in Romanian), Editura HGA, București, 189 p.

Stematiu, D., Ionescu, Ș. (1999), Siguranță și risc în construcții hidrotehnice (Safety and risk in hydrotechnic constructions - in Romanian). Editura Didactică și Pedagogică, București.

Şerban, Gh. (2007), Lacurile de acumulare din bazinul superior al Someşului Mic. Studiu hidrogeografic (Lakes from the Someşul Mic river upper basin. Hydrogeographic study - in Romanian). Edit. Presa Universitară Clujeană, Cluj-Napoca, 236 p.

Şerban, Gh., Pandi, G., Hattemer, C., Vinet, F. (2009), Flood prone areas to 5% and 1% probability of flow in Someşul Rece-sat area downstream from the hydraulic intakes from the Someşul Rece river – Apuseni Mountains (in Romanian). Hidrotehnica, nr. 2, Bucureşti.

Şerban, Gh., Rus, I., Vele, D., Breţcan, P., Alexe, M., Petrea, D. (2016), Flood-prone area delimitation using UAV technology, in the areas hard-to-reach for classic aircrafts: case study in the north-east of Apuseni Mountains, Transylvania. Natural Hazards, Springer Science+Business Media Dordrecht, Volume 82, Issue 3, DOI 10.1007/s11069-016-2266-4, pp. 1817-1832.

Zagonjolli, M. (2007) Dam Break Modelling, Risk Assessment and Uncertainty Analysis for Flood Mitigation (doctorate thesis). Delft University of Technology, Netherlands.

*** (1992) Atlasul Cadastral al Apelor din Romania (Cadastral Atlas of the Waters in Romania - in Romanian), Ministerul Mediului și Aquaproiect, București.

*** (2010) Guidelines for dam breach analysis, Departament of Natural Resources Division of Water Resources, February 10.

*** HEC (2012). HEC-GeoRAS – An extension for support of HEC-RAS using ArcGIS, CPD-83, May 2012. Hydrologic Engineering Center, Institute for Water Resources, U.S. Corps of Engineers, Cameron T. Ackerman.

*** (2014) Using HEC-RAS for Dam Break Studies, US Army Corps of Engineers. Hydrologic Engineering Center, TD-39

*** HEC (2016) HEC-RAS River Analysis System, Hydraulic Reference Manual, Version 5.0, CPD-69 February 2016. Hydrologic Engineering Center, Institute for Water Resources, U.S. Corps of Engineers, Gary, WE, Brunner

*** HEC (2016) HEC-RAS River Analysis System, User's Manual, Version 5.0, February 2016. Hydrologic Engineering Center, Institute for Water Resources, U.S. Corps of Engineers, Gary, WE, Brunner, CEIWR-HEC.

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Playing with water – An introduction to ex-perimental hydrology

Gabriel MINEA[1,2*], Jesús RODRIGO COMINO[3,4], Gabriela MOROŞANU[5,6]

[1]Research Institute of the University of Bucharest, University of Bucharest, 36-46 Bd. M. Kogălniceanu, Sector 5, 050107, Bucharest, Romania
[2]National Institute of Hydrology and Water Management, 97 E Bucureşti - Ploieşti Road, Sector 1, 013686, Bucharest, Romania
[3]Instituto de Geomorfología y Suelos, Department of Geography, University of Málaga, 29071, Málaga, Spain
[4]Physical Geography, Trier University, 54286 Trier, Germany
[5]Faculty of Geography, University of Bucharest, 1 Nicolae Bălcescu Avenue, Sector 1, 010041, Bucharest, Romania.
[6]Institute of Geography, Romanian Academy, 12 Rue Dimitrie Racoviță, Sector 2, 023994, Bucharest, Romania
* *Corresponding author*: gabriel.minea@hidro.ro

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Abstract

Water is the most important resource for the humankind, thus understanding hydrological processes could be considered a vital task. Therefore, the main aims of this papers are to assess: (i) the current status of hydrologic field experiments; (ii) the techniques and the stages of the field hydrologic experiments at the micro-scale/plot-scale. Microscale hydro-logical studies are important both socially and - economically as they emphasize the role of key factors (e.g. slope) in the utiliza-tion of water resources, the identification of critical hydrological thresholds for mobiliz-ing, the propagation of soil particles in water flows and also the time it takes for pesti-cides, nutrients, and heavy metals to be mobilized. The key to conducting a success-ful hydrological microscale experiment lies in performing repeated at-tempts in the field. From an economic point of view, expedition (temporary) hydrologic field experiments are beneficial, as they shorten the working peri-od and reduce the financial costs of the data acquisition process.

One of the challenges of experimental hy-drology is the manipulation of "upscaling" or the statistical approach taken towards gath-ering and processing data.

Keywords: *hydrologic experiment, field, plot scale, runoff*

Rezumat. Experimente cu apa - Introducere în hidrologia experimentală

Apa este cea mai importantă resursă pentru omenire, prin urmare înțelegerea proceselor hidrologice poate fi considerată o sarcină vitală. Astfel, obiectivele principale ale acestei lucrări sunt: (i) stadiul actual al experimentului hidrologic de teren; (ii) tehnicile și etapele experimentului hidrologic de teren la mi-croscară (scara parcelei). Studiile hidrologice la microscară sunt importante, atât din punct de vedere social, cât și din punct de vedere economic, deoarece subliniază rolul factorilor condiționali (de ex. panta) în utilizarea resurselor de apă, în bugetul sedimentelor (identificarea pragurilor hidrologice critice pentru mobilizarea și propagarea fluxului de particule de sol) precum și timpul necesar pentru propagarea pesticidelor, a substanțelor nutritive și a metalelor grele. Cheia pentru a efectua un experiment hidrologic de succes la microscară constă în realizarea de încercări repetate în teren. Din punct de vedere econom-ic, experimentele de teren, expediționare (tem-porare) sunt benefice, deoarece scurtează perioada de lucru și reduc costurile financiare ale procesului de achiziție a datelor. Una dintre provocările hidrologiei experimentale este manipularea "upscaling" sau abordarea statis-tică pentru colectarea și prelucrarea datelor.

Cuvinte-cheie: *experiment hidrologic, teren, scara parcelei, scurgere lichidă*

Introduction

An experiment is a scientific concept about a test or a simulation/manipulation for the purpose of discovering something unknown, proving an impact, exploring an effect, or validating a hypothetical principle (Hinkelmann and Kempthorne, 2008).

Experimental research can provide a good basis for understanding the mechanisms of processes (Huang et al., 2015), and for making future predictions (e.g., water budget; erosion rates).

The principle of an experiment involves studying the relationship between independent variables (spatially and temporally represent inputs) and dependent ones (output).

Conducting an experiment may also contribute to answering some qualitative questions and the results may lead to finding optimized solutions (Dear, 2015). History has recorded many valuable and well known famous experiments, such as those carried out by Archimedes, a Greek physicist, engineer, inventor, and astronomer (showing us that an object immersed in water always displaced a volume of water equal to its own volume); by the English physicist and mathematician Newton (who uncovered the law of universal gravitation, which states that a particle attracts every other particle in the universe using a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them); and by the Russian physiologist Pavlov (the conditioned reflex experiment) etc.

In almost every discipline, science development requires experiments. The main areas of activities which necessarily require field experiments are biology, chemistry (e.g., cosmetics; pharmacology) and technology in its broadest sense (automotive, robotics etc.). In earth sciences, experiments can be also performed in the following disciplines among others:

- ecology: chemical transport (urea) in unsaturated soils; nutrients (Neagoe et al., 2014; Păun et al., 2015);
- geomorphology (Huang et al., 2015; Cantón et al., 2018);
- environmental science and physical geography (Benavides-Solorio and MacDonald, 2001);
- pedology (Mircea et al., 2015; Laufer et al., 2016);
- agronomy (Dincă et al., 2012);
- hydrology (Stanciu and Zlate, 1988; Gu et al., 2013).

A hydrologic experiment is a complex process, as it intentionally imposes a treatment on a sample plot, resulting in the collection of hydrometric data, which must be subject to rigorous analysis for validation (Ma et al., 2017).

Due to their complexity, experimental field studies require a broad spectrum of knowledge from different disciplines, such as hydrology, pedology, phytology etc. (Song et al., 2015). Hydrological experiments can be performed in the laboratory (short term) or, most often, in the field with two working regimes: stationary (quasi-permanent), or expeditionary (temporary) (Wescoat, 2017).

From an economic point of view, the cost of maintaining experimental or representative hydrological stations involves high financial efforts and time-consuming. Often, due to economic issues, some hydro-meteorological activities are being reduced, and one of the most pressing is the closure of the experimental basins (EBs) (Toebes and Ouryvaev, 1970).

For example, in Russia, after 50 years, the Kolyma Water-Balance Station (1948), a unique scientific research hydrological and permafrost catchment EB, was closed in 1997 (Makarieva et al., 2018). Also, in Romania, the number of representative basins in 2018 was reduced to 14, compared to 40, as they existed in the 1980 (Blidaru, 1980). A fortunate exception is the most long-lived and fully equipped EB with a focus on hydrological research in Romania, namely the Voinești Experimental Basin – the former Station for the Experimental Hydrology of Voinești - which started around 1964 (Minea et al., 2018).

Plot-scale experimental studies are designed to understand interrelationships between processes involving hydrological, ecological, and geomorphological factors (Sheng, 1990; Linsley, 2009). In this respect, Boix-Fayos et al. (2006), with regards to issues pertaining to soil erosion, and field plot experiments have identified and analyzed several "*restrictive*" factors regarding the suitability and performance of a field experimental design e.g.:

- temporal and spatial scales of measurements,
- the representation and disturbance of natural conditions,
- the complexity of ecosystem interactions.

In fact, there is no standard methodology regarding the study of hydrological processes by means of field experiments (infiltration, runoff, and erosion rates), but there are a big number of examples of good practices, such as Toebes and Ouryvaev (1970); Hudson (1993); Humphry et al. (2002). The current hydrometric technique evolved so that changes in time resolution and new measurements emerged (e.g., the ability of water level sensors to obtain and store a precise data).

Therefore, in this paper, we seek to assess: (i) the current status of hydrologic field experiments; (ii) techniques and phases of the field hydrological experiments at plot-scale. We also discuss a number of "raised issues" (such as plot scale size, synthesis or a regionalized perspective) in the research literature and field experiments.

Research method

A great deal of hydrologic experimental work involves understanding the experimental setup. Based on the literature review background and personal field observations and experiments (setup or design) we depicted the most important steps to be followed in hydrologic field experiments.

The main scientific method consisted in literature screening of a number of references found in scientific databases such as Scopus and ISI of Web Science. The methodological approach of this paper is based on literature interpretative (office) and exploratory (field) activities.

The literature review in experimental hydrology is one of the research branches of the hydrological sciences and represents the basis for studies of observation, understanding, and prediction of water resources processes (Rui et al., 2013). The element that stands out is the experiment itself.

Hydrologic experiments might be classified according to different criteria, such as domain, scale (size); place (in the laboratory and/or on the field).

Field experimental hydrology

A field hydrologic experiment should facilitate the testing of several hypotheses - an analysis of a rainfall event that can be tested by experimentation – and allow for identifying solutions and for making predictions), (Fig. 1).

The overriding principle for experimental design (a runoff plot up to a block of runoff plots) is to keep the setup as simple as possible (Kinnel, 2016).

Figure 1: Experimental aspects with micro-portable rainfall simulators were set up in the field to simulate rainfall events on plots receiving runoff, suspended load, and sheep manure (Aldeni hillslopes, 2017, Source: G. MINEA)

For a microscale experiment, the researcher should use e independent variables (e.g., rainfall intensities, soil moisture; nutrients concentration), in order to observe the effects on the dependent variables and establish the causal relationship between variables (e.g., precipitation-runoff) (Bagarello et al., 2014; Prima et al., 2018). Sheng (1990) claims that standardization of plot design and management practices should be considered in order to avoid mistakes. In order to be valid, a hydrologic experiment must essentially have the following three characteristics (Blume et al., 2017):

- Be representative;
- Allow for duplication (manipulation/control; comparison of different measures);
- Be adequate for undergoing a statistical treatment (e.g., linear regressions, ANOVA).

The control refers to the use of control group and controlling the effects of extraneous variables on the dependent variable in which researcher is interested.

Hydrologic scale area

The hydrologic scale area can be distinguished into different groups such as microscale (1 sq cm → 1 sq km - simulation of elementary hydrological processes), mesoscale (1 sq km →1 Mio sq km - Continents), and macroscale (1 Mio sq km → Global), (Figure 2). The problem of the scales has been considered a crucial topic among the hydrological scientific com-munity (Dooge, 2013). The size of experimental plots can vary depending on the goal of each research:

- micro-plots (1 sq cm up to one or two square meters, known as monolith);
- small-scale (e.g. ~100 sq m);
- hillslopes/field plots (e.g., 1 ha up to 1 sq km) (Becker and Nemec, 1987; Hudson, 1993).

Blöschl and Sivapalan (1995) considered that small length scales are associated with small time-scales or hydrological processes at the pedon scale. Also, other significant lengths and time scales for hydrology process sizes (e.g., the experimental plot: 10 m length and 10 s time) were elaborated by Dooge (1986). Hydrologic microscale area can vary from plot to the basin (small catchment):

- **Microplot** (used for studying runoff-infiltration, erosion, etc.). For example, Kidron (2007) analyzed runoff yield for measuring over crusted (i.e., surfaces covered by 1–3 mm of cyanobacterial crust) and scalped 3.6-6.3 sq m plots at the Hallamish dune field (Negev Desert, Israel); also, Sui et al. (2016) used treatments of control and micro-basins with block space of 65 cm, 75 cm, and 85 cm. Malvar et al. (2008) selected various monitored runoff and erosion following wildfires on bounded plots of the same dimensions as the plots (0.28 sq m). It is also remarkable that Seitz et al. (2016) determined sediment delivery and runoff volume using micro-scale runoff plots (0.4 m x 0.4 m);

- **Plots**, commonly used for studying runoff, infiltration, snowmelt, erosion, and sediment production processes); pan evaporimeter (Stan et al, 2016) or for installing lysimeters (Matušek et al., 2016);

- **Basin** or - Experimental Basins (EBs): it uses to serve primarily a research tool and represents the best facility for teaching practices of collection, handling, and analysis of hydrometrical data (UN-ESCO, 1983). From a hydrological point of view, EBs are typically natural laboratories, which play an important role in understanding the dynamics of genetic (natural or simulated rainfall) and key (soil, land use, vegetation type, anthropogenic activities, etc.) factors that influence the overland flow, suspended sediment discharge (Minea and Moroşanu, 2014; 2016) and connectivity processes (Keesstra et al., 2018). A typical example of the experimental hydrographic basin is the Valdai Scientific-Research Hydrological Laboratory, also named Valdai Branch of the State Hydrological Institute (SHI), Russia - established in the 1930's (Uryvaev, 1953, quoted in Gu et al., 2013).

In Romania, experimental research designs have been set up in several geographical regions in particular to study the dynamics of soil erosion under a variety of land-uses. The opening of experimental centers/basins (e.g., Cean, Perieni, Podu-Iloaiei, Aldeni) during the 5–6th decades of the twentieth

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century created favorable conditions for more in-depth studies, which provided an important insight into the succession of agents-processes-forms, allowing the first empiric quantitative evaluations on landslide morphodynamics (Rădoane and Vespremeanu-Stroe, 2016).

Hydrologic scale time

The relationship between the microscale and tem-poral process scales in hydrology is founded upon the intensity of various phenomena and the antecedent conditions (Kikuchi et al., 2015).

The most important element that impacts the time scale of a hydrologic experimental study is determined by the runoff plot characteristics (Skøien et al., 2003), such as the size, shape, and orientation (Bagarello et al., 2013).

The lifetime of runoff plot processes can span from a few seconds (Hortonian flow) to several hours (see Fig. 2). It is safe to affirm that the shortest durations are specific to the field experiments based on "*events time*" (Fig. 2). There are also longer runoff plot processes, taking up to 24h and which can be found on soil water balance plots for subsurface and base flow (Figure 2). All characteristic space-time scales need to be interpreted with caution (Skøien et al., 2003).

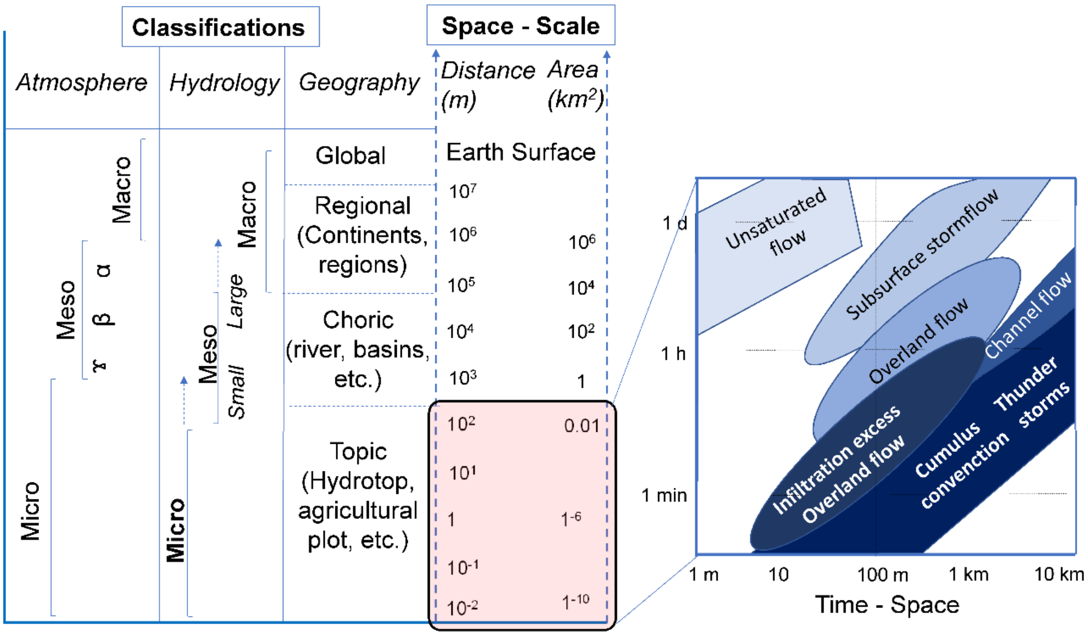

Figure 2: Classification of time-scales and associated activities in hydrology (from Becker and Nemec, 1987) with a focus on minimum time-space characteristic at event scales (from Skøien et al., 2003)

Techniques and steps of the field hydrologic experiment

The scientific way to fulfill every objective of a hydrological study is by doing continuous measurements of variables and field observations.

Also, great attention should be paid to reduce efforts aimed at minimizing the effects of failures during the experiment.

Instrumentations – For the identification of runoff processes at micro-scale, rainfall simulators and micro-simulators may be used (Iserloh et al., 2013). Preferential flow can be followed by dye tracers (e.g., Brilliant Blue FCF) (Pecly and Fernandes, 2017; Stefano et al., 2018). The choice of automatic devices (e.g., water level recorders, sediment samplers) must be made depending on the purpose and the budget of the study (Diyabalanage et al., 2017; Mohammadkhan et al., 2011). Usually, only robust equipment should be chosen, for which the repairing and maintenance service is readily available (Sheng, 1990). Complementary, manual data collections using simple devices/ techniques are also necessary (e.g., soil probes; sediment samples) (Taguas et al., 2015, 2010).

Measurements – are the main operations and the direct way through which quantitative data are pro-duced (e.g., rainfall depth; discharge series) with regard to the causal effect between independent and dependent variables. Hydrologic data stages concern the collecting and analyzing hydrometric data and the examination of the effect of an independent variable on a dependent variable (Higson and Singer, 2015). A good hydrologic dataset (quantitative and qualitative data series) involved in experimentation allows for results' validation and may be up-scaled and/or generalized by means of extrapolation (Ben Slimane et al., 2015; Merchán et al., 2018).

Observations - are complementary, systematic type of activity consisting of attentively watching and examining phenomena (e.g., time concentration, river bank degradation, etc.). The observer, based on an established protocol, must collect, during the experiment, the information that would highlight any inconsistencies between rainfall, infiltration and flow (e.g., lag time: peak discharge time) (Biddoccu et al., 2016; Evans, 2005).

Hydrometric data are valuable, demanding important capital and human resources (Hamilton, 2012). The quality and seriousness of the observer and/or researcher are the keys to the success of an experiment. Techniques to remember when performing observations:

- field observation sheet should provide supplementary information (notes) regarding atmospheric phenomena, land use changes, morphological landscape evolution etc. (Cerdà et al., 2018).
- field photograph - complements the informational table by capturing important moments in time (e.g., rainfall drop, splash erosion, infiltration time, runoff, and surface storage during a natural or artificial rainfall) as well as documents details about the space and require extensive note taking (Marzen et al., 2015).

Automated (measuring) activities need to be duplicated by systematic observations in order to avoid loss of information (e.g., leakage times, pipe collector does not clog the grass or clump). These observations must be carried out permanently throughout the experimental period (rainfall-runoff, snowmelt-runoff) in order to allow the intervention in accidents in order to prevent damage to installations and the failure of experiments.

Failure of experiments

In the scientific world, it is admitted that "*failure to reproduce results is 'a normal part of how science works*" (Open Science Collaboration, 2015). Failures of hydrologic experiments are a part of fieldwork. When planning a hydrological experiment, it should be considered that any field experiment is vulnerable. The vulnerability can occur when the analysis of the effect associated with technical and climatic factors does not take into account all the means of prevention, elimination/avoidance. Possible cause of failure during experiments:

- from the technical point of view: it is not possible to have absolute control over extraneous variables (e.g., nozzle clogging of rainfall simulator); instrumental errors (accidental loss of measured data; clogging water tanks and wrecking water levels; mistaken setting of the data logger);

- environmental: field-based exploitation requires knowledge of weather forecasts in order to avoid wind influence through windshield use and the effect of high temperatures (high evapotranspiration); the impossibility of varied hydrological testing of land plots with various soil properties and with different slopes; or destruction of devices due to animals or insects.

Steps of the field hydrologic experiments

The scientific methodology of hydrologic field experiment involves a series of steps that are used to investigate a natural or simulated event. The independent variable of microscale hydrologic studies is the rainfall or snowmelt event, which makes possible the research of different hydrologic parameters: infiltration rate, runoff discharges or volume, lag time, erosion rate. A protocol should be followed when performing an experimental study (Humphry et al., 2002; Kibet et al., 2014). The stages of the hydrological field experiment are as follows: plot homologation and instrumentation (Fig. 3). Scientific homologating of field plot should consider two criteria: representativity and accessibility (Stroosnijder, 2005).

A runoff plot must be considered representative of a basin if it meets a few criteria (Kavian et al., 2017; Wirtz et al., 2010): it is relatively homogeneous in soil and vegetation and exhibits uniform physical characteristics. Also, the soil use under a plot may be deliberately modified for study purposes, e.g., an hydrohill catchment with 512 square meters of concrete aquic-lude (Weizu and Freer, 1995).

Once the research objective has been established (e.g., quantitative identification of intensive grassland erosion), maps and site plans will be analyzed and field-based mapped to identify site variants (Cunha et al., 2017). After finalizing the chosen variant, the topographic elevation of the approved land shall be carried out at a scale of 1: 100 - 1:2000, depending on the size and number of parcels.

The plots, regardless of their number (a runoff plot; a paired-runoff plot; a block runoff plots), will be placed with the large side perpendicular to the level curve, even if it is not parallel to the parcel plot (Boix-Fayos et al., 2006). The cardinal orientation of one of the small sides must be northward. Thus, a pair of parcels may have the shape of a valley according to the shape of the land.

When placing plots, one should also consider:

- the road network accessibility;
- the agreement on land accessibility, regardless of ownership (public/private);
- avoiding the influence of adjacent and unwanted factors (e.g., uses and experiments on adjacent plots, adduction network, evacuation network, cabinets with appliances, etc.).

All adjacent experimental runoff plots will be mapped at the right/adequate scale using conventional signs so as to create a detailed and overall picture of the experimental area/perimeter.

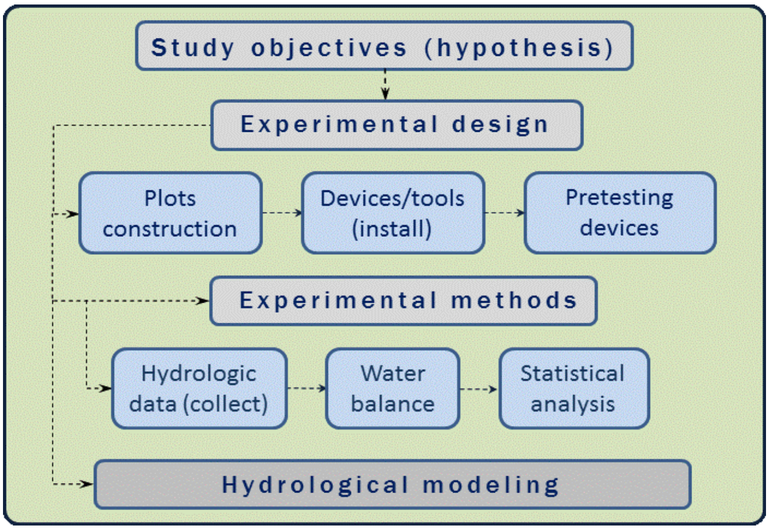

Figure 3: Workflow of the hydrological experiment protocol

Hydrological field experiment protocol

The protocol of a hydrological field experiment for the rainfall-runoff study describes how it will be experimented and should include the following elements (Fig. 3):

a) set a hypothesis - desk documentation - establish-ing the hypothesis and the experimental method (e.g., what is the effect of vegetation on the forma-tion of water resources, how it affects the chemical concentration of the fruit trees, the water in the soil, the anthropogenic perturbation of the hydro-logic cycle); literature review books and papers, topographic and soil vegetation maps, aerial images, guidance and any other sources relevant in relation to the research problem being investigated (perform simulations for products; evaluate, interpret and justify simulation results);

b) establish the experimental protocol:

- choosing the members of the experimental team (observer/technician/hydrologist) and setting work tasks;
- geomorphological condition: slope, aspect, land use; accessibility;
- plot setting (dimensioning; round and rectangular shape; arrangement);
- vegetation study (appearance; cover);
- setup of the necessary equipment for measurements (water level sensor, volumetric water content sensors, label collection bottles) and observations (land plotting guide);
- proper choice, design and/or dimensioning of tools for dealing with extreme situations (e.g., water tanks can be clogged quickly when erosion rates are high);

c) planning of the experiments (establishing the calendar and a minimum and maximum number of experiments with the artificial rainfall installation in relation to the objectives of the research; artificial rain intensity: 0.5 mm/min, 1 mm/min, 2 mm/min); weather and environment conditions research; consultation of weather forecasts to avoid weather conditions that are unfavorable to the experiment, e.g., intense wind; knowledge of antecedent conditions, e.g., API3, soil moisture);

d) field setup - because the validity and repeatability of an experiment are directly affected by its construction and/or execution, setup and installation of devices, taking great care when creating the experimental design is very important; pretesting available tools/devices (e.g., setup; calibration; control measurement; data tests download);

e) test the hypothesis – for example, performing a rainfall simulation; repeating the experiment will extend the hydrologic series, and minimize the effect of experimental errors and reach a more accurate conclusion;

f) analyze the results (water balance, statistical analysis, hydrologic modeling) and write the outcomes, communicate conclusions respectively.

Challenges and social awareness of hydrological experiment fields

As we above-mentioned, hydrological experiments under filed conditions allow us describing the main water processes and issues at different spatiotemporal scales of the most important natural source for the humankind and ecosystems. However, despite the increasing number of publications and diversity of methods as confirmed several editors of the most important hydrological journals (Quinn et al., 2018), further work is still necessary in order to consider the hydrology as a policy-relevant science (Takeuchi, 2004).

As several authors confirmed, soil erosion (García-Ruiz et al., 2013), water pollution (Liu et al., 2017) or flash floods (Alaoui et al., 2018) among others, do not have clear patterns, origins and control measures and further research must be conducted using hydrological experiments under field conditions.

The use of experiments in hydrology also allows us including an obviated key factor in earth science stu-dies, the human impacts (Lu et al., 2018). Hydrologists and related researchers should pay attention to other disciplines such as geomorphology (Seeger, 2017) or soil science (Rodrigo-Comino et al., 2017) in order to make more consistent their results combinating different points of view and increasing the representativity.

Conclusion

In this paper, the manners of obtaining hydrological data at the microscale, as well as the protocols of a hydrological (rainfall-runoff) field experiment were indicated.

Runoff plots are important hydrometric tools for hydrological studies. From an economic point of view, expedition (temporary) hydrological land experiments bring benefits as they shorten the working period and reduce the financial costs of the data acquisition period. The key to a good hydrological experiment at microscale consists of repeated attempts in the field (pretests, carefully designed and maintained) and seriousness.

One of the challenges of experimental hydrology is the manipulation of "*upscaling*" data (see Cantón et al., 2018) generalized by extrapolation, and statistical approach. Dooge (1986) depicts that "*a great contrast between statistical physics and statistical hydrology in regard to the sizes of the aggregates involved and, in the fact, that the hydrological phenomena of major interest involve transient rather than equilibrium behavior*."

However, from event scales of minutes to hours at microscales, quantifying extreme rainfall rates remains a challenge.

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References

Alaoui, A., Rogger, M., Peth, S., & Blöschl, G. (2018). Does soil compaction increase floods? A review. *Journal of Hydrology*, 557, 631–642.

Bagarello, V., Castellini, M., Di Prima, S., & Iovino, M. (2014). Soil hydraulic properties determined by infiltration experiments and different heights of water pouring. *Geoderma*, 213, 492–501.

Bagarello, V., Ferro, V., Giordano, G., Mannocchi, F., Todisco, F., & Vergni, L. (2013). Predicting event soil loss from bare plots at two Italian sites. *CATENA*, 109, 96-102.

Becker, A., Nemec J. (1987). Macroscale hydrologic models in support to climate research. The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources, *Proc. Vancouver Symp*., August 1987, IAHS Publ. no. 168 Edited by: Solomon, S. I., Beran, M. and Hogg, W. 431–445.

Ben Slimane, A., Raclot, D., Evrard, O., Sanaa, M., Lefevre, I., & Le Bissonnais, Y. (2015). Relative contribution of rill/interrill and gully/channel erosion to small reservoir siltation in Mediterranean environments. *Land Degrad. Develop*., 27, 785–797.

Benavides-Solorio, J., & MacDonald, L. H. (2001). Post-fire runoff and erosion from simulated rainfall on small plots, Colorado Front Range. *Hydrological Processes*, 15(15), 2931-2952.

Biddoccu, M., Ferraris, S., Opsi, F., & Cavallo, E. (2016). Long-term monitoring of soil management effects on runoff and soil erosion in sloping vineyards in Alto Monferrato (North–West Italy). *Soil and Tillage Research*, 155, 176–189.

Blidaru, S. (1980). *Studii de hidrologie,* Institutul de Meteorologie şi Hidrologie, Bucureşti.

Blöschl, G., & Sivapalan, M. (1995). Scale issues in hydrological modelling: a review. *Hydrological processes*, 9(3-4), 251-290.

Blume, T., Meerveld, I. van, & Weiler, M. (2017). The role of experimental work in hydrological sciences – insights from a community survey. *Hydrological Sciences Journal*, 62, 334–337.

Boix-Fayos, C., Martínez-Mena, M., Arnau-Rosalén, E., Calvo-Cases, A., Castillo, V., & Albaladejo, J. (2006). Measuring soil erosion by field plots: understanding the sources of variation. *Earth-Science Reviews*, 78(3), 267-285.

Cantón, Y., Rodríguez-Caballero, E., Chamizo, S., Le Bouteiller, C., Solé-Benet, A., & Calvo-Cases, A. (2018). Runoff Generation in Badlands. In *Badlands Dynamics in a Context of Global Change* (pp. 155-190).

Cerdà, A., Rodrigo-Comino, J., Novara, A., Brevik, E.C., Vaezi, A.R., Pulido, M., Giménez-Morera, A., & Keesstra, S.D. (2018). Long-term impact of rainfed agricultural land abandonment on soil erosion in the Western Mediterranean basin. *Progress in Physical Geography: Earth and Environment*, 1-18,

Cunha, N.S., Magalhães, M.R., Domingos, T., Abreu, M.M., & Küpfer, C. (2017). The land morphology approach to flood risk mapping: An application to

Portugal. *Journal of Environmental Management*, 193, 172–187.

Dear, P. (2015). Experiment in Science and Technology Studies, in: Wright, J.D. (Ed.), *International Encyclopedia of the Social & Behavioral Sciences (Second Edition)*. Elsevier, Oxford, 576–581.

Dincă, V., Jinga, I., Stoica, G.M., Vâlsan G., Mandache V., Uberti M., Fierbinţeanu A., & Meluţ L. (2012). Research on drought tolerance of pioneer and Fundulea Institute top comercial cornhybrids tested in different pedo-climatic zones of the south eastern of Romania. *Scientific Papers. Series E. Land Reclamation Earth Observation & Surveying, Environment Engineering*, Vol. I, ISSN-L 2285-6064, 16-19.

Diyabalanage, S., Samarakoon, K.K., Adikari, S.B., & Hewawasam, T. (2017). Impact of soil and water conservation measures on soil erosion rate and sediment yields in a tropical watershed in the Central Highlands of Sri Lanka. *Applied Geography*, 79, 103–114.

Dooge, J.C.I. (2013). *Scale Problems in Hydrology, in: Reflections on Hydrology: Science and Practice*. American Geophysical Union (AGU), 84–145.

Evans, R. (2005). Monitoring water erosion in lowland England and Wales - A personal view of its history and outcomes. *CATENA*, 64, 142–161.

García-Ruiz, J.M., Nadal-Romero, E., Lana-Renault, N., & Beguería, S. (2013). Erosion in Mediterranean landscapes: Changes and future challenges. *Geomorphology*, 198, 20–36.

Gu, W. Z., Frentress, J., Lu, J. J., & Liu, J. F. (2013). Current Challenges in Experimental Watershed Hydrology. *INTECH Open Access Publisher*. 299-333.

Hamilton, S. (2012). The 5 Essential Elements of a Hydrological Monitoring Programme, Bulletin nº: Vol 61 (1) – http://public.wmo.int/en/bulletin/5-essential-elements-hydrological-monitoring-programme

Higson, J.L., & Singer, M.B. (2015). The impact of the streamflow hydrograph on sediment supply from terrace erosion. *Geomorphology*, 248, 475–488.

Hinkelmann, K., Kempthorne, O. (2008) Design and Analysis of Experiments, Volume I: Introduction to Experimental Design, Second edtion. *Wiley - Interscience. A John Wiley & Sons, Inc.*, Publication, New Jersey.

Huang, Y., Chen, X., Luo, B., Ding, L., & Gong, C. (2015). An experimental study of rill sediment delivery in purple soil, using the volume - replacement method*. PeerJ*, 3, e1220, DOI 10.7717/peerj.1220.

Hudson, N.W. (1993). Field measurement of soil erosion and runoff. FAO Soils Bulentin, 68, Roma.

Humphry, J.B., Daniel, T.C., Edwards, D.R., & Sharpley, A. N. (2002). A portable rainfall simulator for plot–scale runoff studies. *Applied Engineering in Agriculture,* 18(2): 199–204.

Iserloh, T., Ries, J.B., Arnáez, J., Boix-Fayos, C., Butzen, V., Cerdà, A., Echeverría, M.T., Fernández-Gálvez, J., Fister, W., Geißler, C., Gómez, J.A., Gómez-Macpherson, H., Kuhn, N.J., Lázaro, R., León, F.J., Martínez-Mena, M., Martínez-Murillo, J.F., Marzen, M., Mingorance, M.D., Ortigosa, L., Peters, P., Regüés, D., Ruiz-Sinoga, J.D., Scholten, T., Seeger, M., Solé-Benet, A., Wengel, R., & Wirtz, S. (2013). European small portable rainfall simulators: A comparison of rainfall characteristics. *Catena*, 110, 100–112.

Kavian, A., Golshan, M., & Abdollahi, Z. (2017). Flow discharge simulation based on land use change predictions. *Environ. Earth. Sci.*, 76, 588.

Keesstra, S., Nunes, J.P., Saco, P., Parsons, T., Poeppl, R., Masselink, & R., & Cerdà, A. (2018). The way forward: Can connectivity be useful to design better measuring and modelling schemes for water and sediment dynamics?, *Science of The Total Environment*, 644, 1557–1572.

Kibet, L. C., Saporito, L. S., Allen, A. L., May, E. B., Kleinman, P. J. A., Hashem, F. M., & Bryant, R. B. (2014). A Protocol for Conducting Rainfall Simulation to Study Soil Runoff. *Journal of Visualized Experiments : JoVE*, (86), 51664. Advance online publication.

Kidron, G.J. (2007). Millimeter-scale microrelief affecting runoff yield over microbiotic crust in the Negev Desert. *Catena*, 70(2), 266-273.

Kikuchi, C.P., Ferré, T.P.A., & Vrugt, J.A. (2015). On the optimal design of experiments for conceptual and predictive discrimination of hydrologic system models. *Water Resources Research*, 51, 4454–4481.

Kinnell, P.I.A. (2016). A review of the design and operation of runoff and soil loss plots. *Catena*, 145, 257–265. https://doi.org/10.1016/j.catena.2016.06.013

Laufer, D., Loibl B., Märländer, B., & Koch, H.J. (2016). Soil erosion and surface runoff under strip tillage for sugar beet (Beta vulgaris L.) in *Central Europe. Soil and Tillage Research*, 162, 1-7.

Linsley, R.K. (2009). Representative and experimental basins where next?/Les bassins représentatifs et expérimentaux—et après?. In *Hydrological sciences bulletin*, 21:4, 517-529

Liu, Y., Engel, B.A., Flanagan, D.C., Gitau, M.W., McMillan, S.K., & Chaubey, I. (2017). A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. *Science of The Total Environment*, 601–602, 580–593.

López-Vicente, M., Quijano, L., Palazón, L., Gaspar, L., & Navas, A. (2015). Assessment of soil redistribution at catchment scale by coupling a soil erosion model and a sediment connectivity index (central spanish pre-pyrenees). *Cuadernos de Investigación Geográfica*, 41, 127–147.

Lu, Z., Wei, Y., Feng, Q., Western, A.W., & Zhou, S., (2018). A framework for incorporating social processes in hydrological models. *Current Opinion in Environmental Sustainability*, 33, 42–50.

Ma, Y., Li, X., Guo, L., & Lin, H. (2017). Hydropedology: Interactions between pedologic and hydrologic processes across spatiotemporal scales. *Earth-Science Reviews*, 171, 181–195.

Makarieva, O., Nesterova, N., Lebedeva, L., & Sushansky, S. (2018). Water balance and hydrology research in a mountainous permafrost watershed in upland streams of the Kolyma River, Russia: a database from the Kolyma Water-Balance Station, 1948–1997. *Earth System Science Data*, 10(2), 689–710.

Malvar, M. C., Prats, S. N., & JP–Keizer, J. J. (2008). Micro-plot scale overland flow generation and soil erosion in two recently burnt eucalypt stands in north-central Portugal, *Proceedings of the 15 IS-CO Congress,* 18-23 May, Budapest.

Marzen, M., Iserloh, T., Casper, M.C., & Ries, J.B. (2015). Quantification of particle detachment by rain splash and wind-driven rain splash. *CATENA*, 127, 135–141.

Matušek, I., Reth, S., Heerdt, C., Hrčková, K., & Gubiš, J. (2016). Lysimeter - a unique tool for monitoring the interactions among the components of environment. *Proceedings of National Aviation University,* 67(2), 69-75.

Merchán, D., Casalí, J., Lersundi, J.D.V. de, Campo-Bescós, M.A., Giménez, R., Preciado, B., & Lafarga, A. (2018). Runoff, nutrients, sediment and salt yields in an irrigated watershed in southern Navarre (Spain). *Agricultural Water Management*, 195, 120–132.

Minea, G., Tudor, G., Stan, F.-I., Ioana-Toroimac, G., & Zamfir, R. (2018). How can the grasslands under rainfall events modify water balance in drought conditions. *Journal of Water and Land Development*. No. 38, 53–65.

Minea, G., Morosanu, G. (2014). Research of water balance at hydrological micro-scale in the Aldeni Experimental Basin (Romania), *Forum geografic. Studii şi cercetări de geografie şi protecția mediului*, Volume XIII, Issue 2, 185-192.

Mircea, S., Petrescu, N., Tronac, A. (2015). Some aspects concerning gully erosion process in small torrential watersheds and its impact on environment. *Carpathian Journal of Earth and Environmental Sciences*. Vol. 10. Iss. 2 p. 115–122.

Mohammadkhan, S., Ahmadi, H., & Jafari, M. (2011). Relationship between soil erosion, slope, parent material, and distance to road (Case study: Latian Watershed, Iran). *Arab J. Geosci.*, 4, 331–338.

Neagoe, A., Stancu, P., Nicoară, A., Onete, M., Bodescu, F., Gheorghe, R., Iordache, V. (2014). Effects of arbuscular mycorrhizal fungi on Agrostis capillaris grown on amended mine tailing substrate at pot, lysimeter, and field plot scale, *Environmental Science and Pollution Research*, Volume 21, Issue 11, 6859–6876.

Open Science Collaboration (2015). Estimating the reproducibility of psychological science. *Science,* 349(6251), aac4716.

Păun, A., Neagoe, A., Păun, M., Baciu, I., & Iordache, V. (2015). Heavy Metal Induced Differential Responses to Oxidative Stress and Protection by Mycorrhization in Sunflower Grown at Lab and Field Scales. *Polish Journal of Environmental Studies*, 24(3), 1235-1247.

Pecly, J.O.G., & Fernandes, S.R.C. (2017). Ancillary device for flow rate measurement using dye tracer technique. *Flow Measurement and Instrumentation*, 54, 274–282.

Prima, S.D., Marrosu, R., Lassabatere, L., Angulo-Jaramillo, R., & Pirastru, M. (2018). In situ characterization of preferential flow by combining plot- and point-scale infiltration experiments on a hillslope. *Journal of Hydrology*, 563, 633–642.

Quinn, N., Blöschl, G., Bárdossy, A., Castellarin, A., Clark, M., Cudennec, C., Koutsoyiannis, D., Lall, U., Lichner, L., Parajka, J., Peters-Lidard, C.D., Sander, G., Savenije, H., Smettem, K., Vereecken, H., Viglione, A., Willems, P., Wood, A., Woods, R., Xu, C.-Y., & Zehe, E. (2018). Joint Editorial Invigorating Hydrological Research through Journal Publications. *Journal of Hydrology and Hydromechanics,* 66, 257–260.

Rădoane, M., & Vespremeanu-Stroe, A. (Eds.). (2016). Landform Dynamics and Evolution in Romania. Springer.

Rodrigo-Comino, J., Senciales, J.M., Cerdà, A., & Brevik, E.C. (2018). The multidisciplinary origin of soil geography: A review. *Earth-Science Reviews*, 177, 114–123.

Rui, X., Liu, N., Li, Q., & Liang, X. (2013). Present and future of hydrology. *Water Science and Engineering*, 6, 241–249.

Seeger, M. (2017). Experiments as tools in geomorphology. *Cuadernos de Investigación Geográfica*, 43, 7–17.

Seitz, S., Goebes, P., Song, Z., Bruelheide, H., Härdtle, W., Kühn, P., ... & Scholten, T. (2015). Tree species identity and functional traits but not species richness affect interrill erosion processes in young subtropical forests. *SOIL Discuss*, 2(1), 701-736.

Sheng, T. C. (1990). Runoff plots and erosion phenomena on tropical steeplands. Research needs and applications to reduce erosion and sedimentation in tropical steeplands. *IAHS Publication*, (192), 154-161.

Skøien, J. O., Blöschl, G., & Western, A. W. (2003). Characteristic space scales and timescales in hydrology. *Water Resources Research*, 39(10).

Song, X., Zhang, J., Zhan, C., Xuan, Y., Ye, M., & Xu, C., (2015). Global sensitivity analysis in hydrological modeling: Review of concepts, methods, theoretical framework, and applications. *Journal of Hydrology*, 523, 739–757.

Stan, F. I., Neculau, G., Zaharia, L., Ioana-Toroimac, G., & Mihalache, S. (2016). Study on the evaporation and evapotranspiration measured on the Căldăruşani Lake (Romania). *Procedia Environmental Sciences*, 32, 281-289.

Stanciu P., Zlate I. (1988). Modelarea matematică a proceselor scurgerii în bazine experimentale şi reprezentative, *Studii şi cercetări, Hidrologie 2*, Institutul de Meteorologie şi Hidrologie, 17-32, București.

Stefano, C.D., Ferro, V., Palmeri, V., & Pampalone, V. (2018). Assessing dye-tracer technique for rill flow velocity measurements. *Catena*, 171, 523–532.

Stroosnijder, L. (2005). Measurement of erosion: Is it possible?, *Catena*, 64, 162–173.

Sui, Y., Ou, Y., Yan, B., Xu, X., Rousseau, A. N., & Zhang, Y. (2016). Assessment of Micro-Basin Tillage as a Soil and Water Conservation Practice in the Black Soil Region of Northeast China. *PloS one*, 11(3), e0152313.

Taguas, E.V., Guzmán, E., Guzmán, G., Vanwalleghem, T., & Gómez, J.A. (2015). Characteristics and importance of rill and gully erosion: a case study in a small catchment of a marginal olive grove. *Cuadernos de Investigación Geográfica*, 41, 107–126.

Taguas, E.V., Peña, A., Ayuso, J.L., Pérez, R., Yuan, Y., & Giráldez, J.V. (2010). Rainfall variability and hydrological and erosive response of an olive tree microcatchment under no-tillage with a spontaneous grass cover in Spain. *Earth Surf. Process. Landforms*, 35, 750–760.

Takeuchi, K. (2004). Hydrology as a policy-relevant science. *Hydrological Processes*, 18, 2967–2976.

Toebes C., Ouryvaev V. (1970). Representative and experimental basins. An international guide for research and practice, A contribution to the International Hydrological Decade, *United Nations Educational, Scientific and Cultural Organization*, Paris.

UNESCO, (1983). Experimental Facilities in Water Resources Education - Technical Papers in Hydrology, A contribution to the International Hydrological Programme, *IHP-II Project B.2.1.4, United Nations Educational, Scientific and Cultural Organization*, Paris.

Weizu, G., & Freer, J. (1995). Patterns of surface and subsurface runoff generation. *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences*, 229, 265-274.

Wescoat, J.L. (2017). Hydrology: History, *in: International Encyclopedia of Geography. American Cancer Society*, 1–9.

Wirtz, S., Seeger, M., & Ries, J.B. (2010). The rill experiment as a method to approach a quantification of rill erosion process activity. *Zeitschrift für Geomorphologie*, NF 54, 47–64.

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Estimation of drinking water supply and its future trends in Varanasi city, India

Vineet Kumar RAI[1], Pravin KUMAR[1], Praveen Kumar RAI[1,*]

[1] Department of Geography, Institute of Science, Banaras Hindu University, Varanasi-221005, U.P., India
* *Corresponding author*: rai.vns82@gmail.com

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Abstract

The current study shows the estimation of drinking water supply, future trends and related issues in Varanasi City, India. Varanasi (from 25^{0}13′N to 25^{0}24′N latitudes and from 82^0 54′E to 83^0 04′E longitude) is one of the most important and historic city located almost in the Middle Ganga valley in the northern plain of India. For the convenience of civic administration, the city is presently divided into 90 wards and for the purpose of extending adequate and safe water supply facilities to the entire area, the city has been divided presently into 16 water supply zones of which 5 zones lie in the trans-Varuna area and the remaining 11 zones in the cis-Varuna area. The present work is based on the secondary sources of data which are obtained from Water Supply Department (Jal Sansthan), Nagar Nigam (Municipal Corporation) of Varanasi. In the first phase of the study, data pertaining to ward wise generation of water supply is collected from Water Supply Department, NNV (Nagar Nigam Varanasi). Informal focused group discussion, PRA (Participatory Action Research), and observation technique were applied to get the first hand information about the water supply scenario in the city. In the second phase of the study, Arc GIS 10.1 software was used to create maps for estimation of water supply management. The population growth in Varanasi from 2011 to 2041 is estimated to have a growth of 21% in 30 years at a rate of 2.25 % per year. This growth rate is considered in the model from 2011 to 2041 to predict the water demand in the city. The data was collected from various municipalities as per the office records. It is estimated that the amount of drinking water requirement forecasted for 2021, 2031 and 2041 is 0.49, 0.76 and 1.17 Billion liters per day respectively in Varanasi City. These data show that with an increase in population, the water demand is also increasing decade after decade. Increasing population growth rate, decreasing surface water resources, overexploitation of groundwater, deterioration of ground water quality and poor sewage treatment are the major water supply related issues in Varanasi city, India.

Keywords: *drinking water supply, overexploitation of groundwater, forecasting method, increasing population*

Rezumat. Estimarea aprovizionării cu apă potabilă și tendințele sale viitoare în orașul Varanasi, India

Studiul actual prezintă estimarea aprovizionării cu apă potabilă, tendințele viitoare și problemele aferente acesteia în orașul Varanasi, India. Varanasi (care se întinde de la 25^{0}13′N la 25^{0}24′N latitudine nordică și de la 82^0 54'E la 83^0 04' E longitudine estică) este unul dintre cele mai importante orașe istorice situate în valea Gangelui mijlociu din câmpia nordică a Indiei. Administrația civică a împărțit orașul în 90 de cartiere și pentru extinderea instalațiilor adecvate și sigure de alimentare cu apă pentru întreaga zonă, orașul a fost împărțit în prezent în 16 zone de alimentare cu apă, din care 5 zone se află în zona trans-Varuna și celelalte 11 zone sunt în zona cis-Varuna. Lucrarea de față se bazează pe sursele secundare de date obținute de la Departamentul de Aprovizionare cu Apă (Jal Sansthan), Nagar Nigam (Societatea municipală) din Varanasi. În prima fază a studiului, datele referitoare la generarea de aprovizionare cu apă a cartierelor sunt colectate de la Departamentul de Aprovizionare cu Apă, NNV (Nagar Nigam Varanasi). Au fost realizate discuții de grup informale, PRA (Studiu de acțiune participativă) și a fost folosită metoda observației pentru a obține informații primare cu privire la scenariul de aprovizionare cu apă din oraș. În a doua fază a studiului, software-ul Arc GIS 10.1 a fost utilizat în vederea creării de hărți pentru estimarea managementului aprovizionării cu apă. Creșterea populației din Varanasi în perioada 2011-2041 este estimată la o creștere de 21% în 30 de ani, cu o rată de 2,25% anuală. Această rată de creștere este luată în considerare în modelul din 2011 până în 2041 pentru a anticipa cererea de apă în oraș. Datele au fost colectate de la diferite municipalități, conform înregistrărilor administrative. Se estimează că, cantitatea de apă potabilă pentru 2021, 2031 și 2041 este de 0,49, 0,76 și respectiv 1,17 miliarde de litri pe zi în orașul Varanasi. Aceste date arată că, odată cu creșterea numărului populației, cererea de apă crește de asemenea de la decadă la decadă. Mărirea ratei de creștere a populației, scăderea resurselor de apă de suprafață, supraexploatarea apelor subterane, deteriorarea calității apelor subterane și tratarea redusă a apelor uzate sunt principalele probleme legate de aprovizionarea cu apă din orașul Varanasi, India.

Cuvinte-cheie: *alimentarea cu apă potabilă, supraexploatarea apelor subterane, metoda de previziune, creșterea populației*

Introduction

Rapid and unplanned urbanization especially in developing countries promotes environment related morbidity including the inability of Municipal Authorities to meet the growing demand of an ever increasing population for basic urban services such as drinking water supply.

On account of rapid increase in urban population, the gap in demand and supply of basic services is increasing continuously. According to the primary source of drinking water reported by Census 2011 nearly 70% households have access to tap water, out of which 62% have access to treated tap water. Thus, nearly 40% of urban households have no access to public supply, and have to depend on other sources of water. Moreover, not all the households that have access to public supply have access to it within the premise. Only 49% of households have access to piped water supply within their premises.

In over 50 years of political independence and economic development, India has not been able to ensure the most basic of human needs – safe drinking water – for all its citizens. Rural areas include the largest number of people without access to safe water but, in common with many developing countries, the fastest growing unserved populations live in urban and peri-urban areas. Given the primacy of drinking water as a national objective (Government of India, 1999) and recent policies of devolution through private sector participation and local governments, we ask: How can urban India alleviate its household level drinking water deprivation, in the near-to-medium term, and in cost-effective ways? This question, and this policy shift, is central to resource planning not only in India, but in many low-income nations struggling to provide universal access to drinking water. No major Indian city has a 24 hour supply of water, with 4 to 5 hours of supply per day as the norm. This compares to the Asian- Pacific average of 19 hours per day supply. These averages conceal a great deal of heterogeneity within cities. Dubey, 1976 in his study of Kaval towns of Uttar Pradesh highlighted the problems of water supply and sewerage system. Singh and Kumra, 1997 have examined the impact of Ganga Action Plan (GAP) launched at Varanasi in June 1986 on the quality of water of river Ganga- main source of water supply in Varanasi city, taking water samples from six maximally used Ghats. Radhakrishna, 2008 in his monograph 'Water supply and sanitation in Indian context' emphasized to increase the capacity of treatment of waste water in cities where sewage treatment plants have been installed. He has advised to install treatment plants in all the cities with a population of more than 100,000 persons. In a survey of Delhi households with in-house connections, Zérah, 2000 finds that 40% had 24 hour supply of water, while more than 25% had under 4 hours a day of service. McIntosh, 2003 notes that consumers without 24-hour supply tend to use more water than those with continuous supply because consumers store water, which they then throw away to replace with fresh supplies each day (Iglesias, 2002).

Under current conditions, all Mediterranean countries also face significant problems due to the unbalanced distribution of water resources, conflicts among users and between countries and it seems most likely that climate change will lead to an intensification of these problems. Projected population growth is a way to measure gaps in water availability. Continued increase in domestic water withdrawals and demands led to the recognition of the importance of water necessary for ecological sustainability (Chaves and Alipaz, 2007). The water balance for the Oueme–Bonou catchment has been calculated for the period of 2002 to 2025, with 2002 as the basis year (Giertz et al., 2010).

Recently, the Geographical Information Systems (GIS) have become an integral and useful tool in spatial and statistical analysis in water resources management (Udovyk, 2006). An attempt has been made in this paper on mapping urban water demands using multiple criteria analysis. The water management framework is necessary when estimating the present and future urban water demands for proper planning, development and management of water resources (Mohan et al., 2011; Chaurasia et al., 2013). Moreover, the anticipated urban water demands and the construction of the water supply and distribution system are essential in development planning of regions (Cihakova, 2006).

Drinking Water Risk assessment calculations assume that an average adult ingests approximately 2.0 l of water per day (Van Engelen et al., 2007). The water demand predictions can be achieved by various techniques, such as: time extrapolation; single coefficient requirement methods; multiple coefficient requirement models; multiple coefficient demand models; and disaggregated water use forecast models (Baumann et. al., 1997; Pradhan, 2003; Mohan et al., 2011). According to a recent report of Central Pollution Control Board (CPCB, 2008) on "State of the Environment-Varanasi" there is an acute shortage of water because the distribution system is not well developed. The finding of the CPCB indicate that supply of water is only 60 lpcd in the Trans-Varuna area which is lower than the prescribed norms.

Study Area

Varanasi enjoys a commanding position on the crescent shaped left bank of the Ganga river (fig.1). The city is located on the proper ridge which forms the northern bank of the Ganga river at a distance of over 5 km (Rai & Nathawat, 2013; Rai & Mohan, 2014). This part of the city is quite above the normal flood level. The city is 76.21m above the sea level. Varanasi (250 13'N to 250 24'N latitudes and from 820 54'E to 830 04'E longitude) is one of the most important and historic city located almost in the middle Ganga valley in the northern plain of India. It is locate at a distance by rail of 696 km from Kolkata, 1505 km from Mumbai, 797 km from Delhi, 143 km from Allahabad, 230 km from Gorakhpur and 301 km from Lucknow- the capital of Uttar Pradesh.

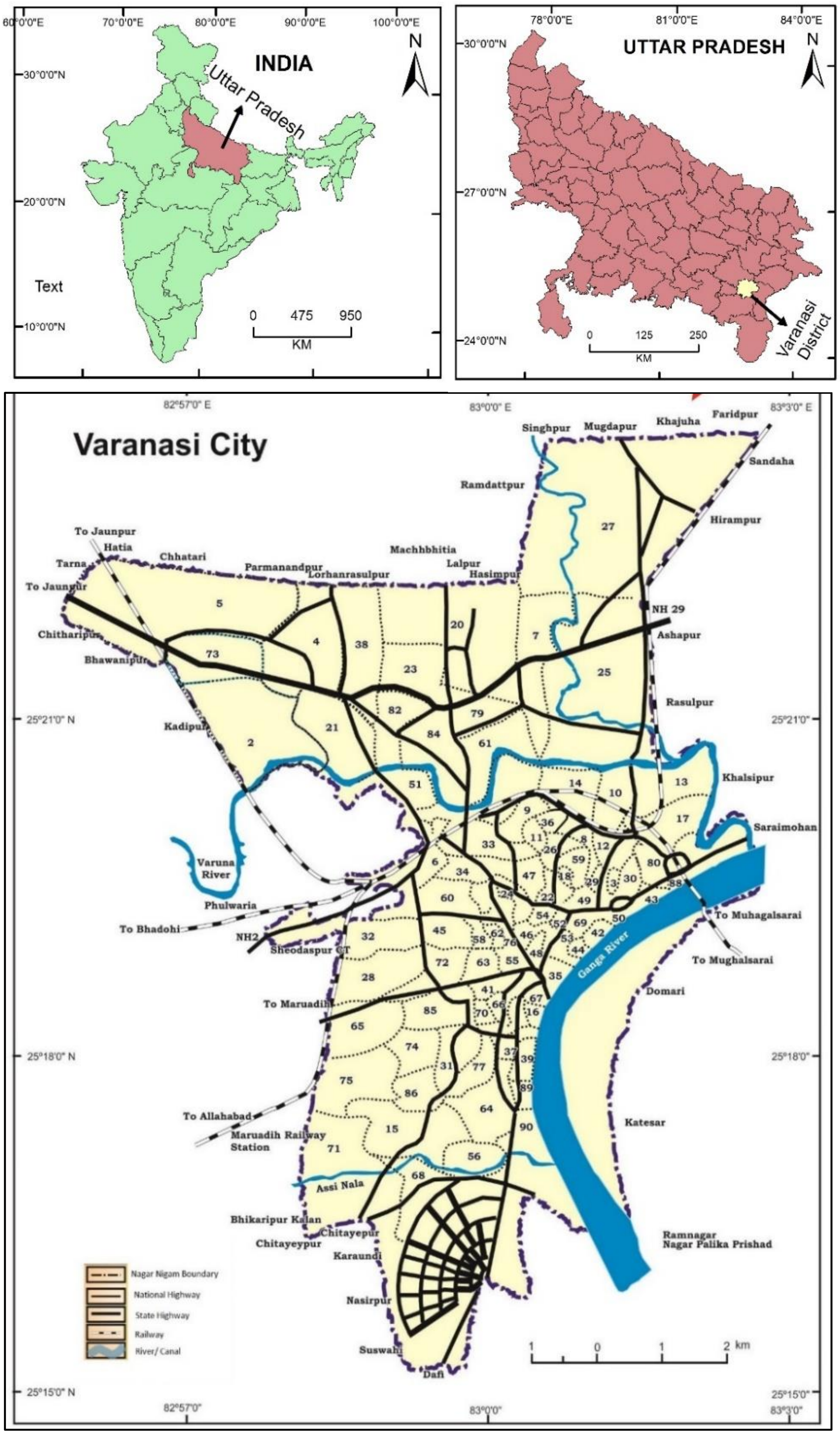

Figure 1: The location of the study area

From the very beginning, the Ganga river is serving as an important route of movement to facilitate the transportation of goods and traffic in addition to water supply to the city and as a natural defence barrier.

For the convenience of civic administration the city is divided into 90 wards and for the purpose of extending adequate and safe water supply facilities to the entire area, the city has been divided presently into 16 water supply zones of which 5 zones lie in the Trans-Varuna area and the remaining 11 zones in the Cis-Varuna area. As per 2011 Census, Varanasi city has a total population of 11, 98,492 (municipal corporation) of which 6, 35,140 are males and 5,63,352 are females. The total number of households in the city were 1,90,835 and the household density was recorded as 24 household/ha. The population density of the city is 150 persons/ha. About 70.30% of the population of city is literate. The sex ratio of the city is of 887 females/1000 males.

Materials and methods

The paper is based on the secondary data sources which are obtained from the Water-Supply Department (Jalkal Vibhag), Municipal Corporation, Varanasi. In the first phase of the study, data pertaining to ward wise generation of water supply is collected from Jalkal Vibhag, Municipal Corporation of Varanasi. Informal focused group discussion, PRA (Participatory Action Research) and observation technique were applied to get the first hand information about the water supply scenario in the city. The secondary data sources include documents of ULB's relevant government reports, documents and study reports, and other similar documents were consulted for writing the paper. The data regarding the population is obtained from the Census office of Lucknow. Data on generation of water supply is calculated by multiplying the urban population by the amount of water demand in Million Liters per Day (MLD) (table 1). In the second phase of the study, ArcGIS was used to create maps for estimation of water supply management. The original map of Varanasi city was scanned and registered/geo-referenced to specify its location by inputting coordinates. Thereafter, the collected data for various water supply zones and locations were given as input parameters for the supply of municipal water management maps for Varanasi city using ArcGIS applications.

Table 1: The current status of water supply demand and supply details

No.	Description	Total
1	Population	17.16 Lack
2	Current Water Demand	257 MLD
3	Water Extracted	---
4	From Ganga River	120 MLD
5	From Deep Tube Wells	190 MLD
6	From Mini Tube Wells	11 MLD
7	Supply Side After Losses	292 MLD
8	Current Deficit	43 MLD
9	Total	321 MLD

Source: Water Supply Department (Jal Sansthan), Varanasi, 2013

Varanasi is divided into 2 district areas Cis-Varuna and Trans-Varuna. The former includes the old city and the areas of Lanka towards south-west and Lahartara zones. The Trans-Varuna area consists of Civil Lines and developing areas of Shivpur, U.P. College, Pandeypur and Paharai Zones. For the purpose of water supply, the city is divided into 16 water supply zones of which 5 zones lie in the Trans-Varuna area and the remaining 11 lie in the Cis-Varuna whereas Lahartara zone lie outside the municipal boundary. Further the whole city has been divided into four zones for the purpose of water supply (table 2).

Table 2: The zone wise distribution of tube wells

Zone	No. of Large Tube wells	No. of Mini Tube wells
North	52	30
South	28	8
Central	37	35
Zone-4	23	7
Total	140	80

Source: Water Supply Department (Jal Sansthan), Varanasi, 2013

The maximum number of tube wells (52) is installed in the north zone owing to non-availability of water supply from Ganga river. Besides the development of the new residential areas, Chetganj (Zone 4) and Dashaswamedh (Zone 4) have only 23 tube wells due to partial supply of drinking water from the Ganga river. There are altogether 140 tube wells which are operated in four zones. The town has adequate perennial source of water in Ganga river, which provides approximately 38% of the total water supply. Another 57% of the water supplied is obtained out from tube wells and remaining 5% is supplied by publicly and privately owned Hand pumps (table 3 & fig. 2).

Table 3: The sources of drinking water supply

Source	Capacity (MLD)	Per cent	Water Supplied
Ganga River	125	38	Water supply to Bhelupur water works
Tube wells	190	57	Jal Sansthan
Hand pumps	15	5	Public and Privately owned
Total Supply	330	100	

Source: Water Supply Department (Jal Sansthan or Jalkal), Varanasi, 2013

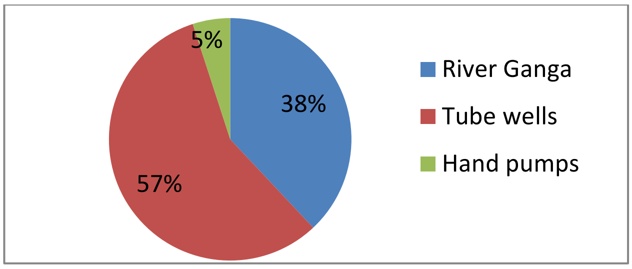

Figure 2: The source of drinking water supply

15% are lost in the water treatment process and 20% are lost in transmission as assumed by the Jal Sansthan. The raw water from the Ganga river is lifted and pumped at Bhadani pumping station and transported to Bhelupur Water Works where it is treated, stored and distributed in the entire Trans-Varuna area and some recently developed localities in Cis-Varuna area. The water is also distributed to different storage tanks dispersed all over the city. There are 17 overhead tanks (capacity, 17.8 mld) along with 7 underground reservoirs. The existing storage capacity is insufficient to take care of the present as well as the future demand of the city. The present distribution system of water supply is more than 100 years old and hence prone to leakages. Sometimes the sewer lines cross the water supply lines posing a risk of contamination of the water supply. It has been estimated that the loss of water through leakage and poor maintenance of pipelines is 99 MLD, i.e. 30% of water is lost due to leakage in pipelines (according to a report of Jal Sansthan). As a result, it creates the situation of deficit water per day in the city.

Looking at the population of the city, the water requirement is approximately 276 MLD but Jal sanathan is able to provide only 231 MLD. Due to leakage (30%) 99 MLD water go as waste. However, a total of 330 MLD water is produced by Jal sansthan. The water is being supplied at the rate of 130 liters per capita per day against the recommended norms of 150 liters per capita per day by CPHEEO. The total domestic requirement for 2011 had been calculated in a spatial domain, using population data and the consumption rate per capita. Data shows that about 156 MLD water is being supplied against the total requirement of about 180 MLD, with a gap of about 24 MLD, there is also marked spatial variation in water demand and supply across the city (table 4). The total water demand per day varies from 0.13 MLD to 0.58 MLD. It is observed in fig. 3 that the high deficit is greater than 0.5 (Requirement of Water Supply-Total Water Supply) and it is is found in Rajghat and Mawaiya. It also indicates that the water supply does not commensurate the required demand for water anywhere in Varanasi City.

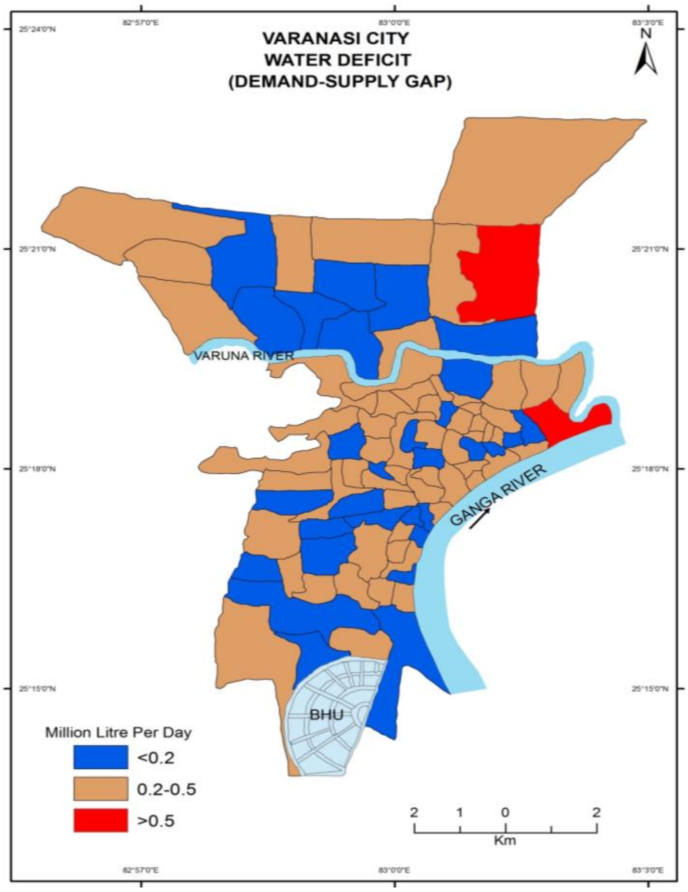

Figure 3: The water deficit (Demand – Supply Gap) within Varanasi city

Table 4: The ward wise water supply, requirement and water deficit in Varanasi City

No.	Name of Wards	Requirement of Water Supply (lpcd)	Water Supply (lpcd)	No.	Name of Wards	Requirement of Water Supply (lpcd)	Water Supply (lpcd)
1	Lahartara	2533500	2195700	46	Benia	2144100	1858220
2	Indrapur	2311650	2003430	47	Ishwargangi	1829100	1585220
3	Chhitanpur	3045450	2639390	48	Harhasarai	1686450	1461590
4	Narayanpur	1317600	1141920	49	Madhemaheshwar	1028100	891020
5	Tarna	2515800	2180360	50	Kameshwar Mahadev	2555550	2214810
6	Nadesar	1876200	1626040	51	Raja Bazar	1783500	1545700

7	Pahariya	2550750	2210650	52	Saptsagar	1994700	1728740
8	Kamalgarha	3155400	2734680	53	Bramhnal	1431750	1240850
9	Kalishahullapur	2439000	2113800	54	Goladinanath	1154700	1000740
10	Jalalipura	2398650	2078830	55	Pandariba	1899600	1646320
11	Rasulpur	1935600	1677520	56	Nariya	2477850	2147470
12	Nawapura	3028200	2624440	57	Pandeyhaweli	2272050	1969110
13	Sareyan	3687300	3195660	58	Lallapura Kalan	2199750	1906450
14	Aliapura	1206000	1045200	59	Basaniya	1570350	1360970
15	Saraisurjan	1505550	1304810	60	Lallapura Khurd	1532100	1327820
16	Madanpura	1930200	1672840	61	Hukulganj	1916250	1660750
17	Rajghat	3879300	3362060	62	Lahangpura	1297950	1124890
18	Natehar	2026800	1756560	63	Luxa	1506250	1218750
19	Ghausabad	2949300	2556060	64	Durgakund	1510950	1309490
20	Ramrepur	2073900	1797380	65	Tulsipur	1749450	1516190
21	Sikraul	1464000	1268800	66	Tillbhandes-hwar	1989300	1724060
22	Daranagar	2438250	2113150	67	Bangalitola	1442850	1250470
23	Taktakpur	2826000	2449200	68	Sunderpur	1506900	1305980
24	Senpura	1276950	1106690	69	Kalbhairav	1675050	1451710
25	Mawaiya	4347900	3768180	70	Rewaritalab	1144200	991640
26	Jaitpura	2253000	1952600	71	Karaudi	2305200	1997840
27	Sarnath	2465700	2136940	72	Sigra	1644900	1425580
28	Shivpurva	2992650	2593630	73	Shivpur	1503300	1302860
29	Baluabir	2370750	2054650	74	Vinayaka	1483350	1285510
30	Salempur	2032800	1762760	75	Bajardiha	2093550	1814410
31	Khojawa	2626800	2276560	76	Sarai-goverdhan	1826100	1582620
32	Lokochhitupur	3510150	3042130	77	Bhelupur	2178150	1887730
33	Dhupchandi	2838450	2459990	78	Katuapura	1353750	1173250
34	Jagatganj	2697750	2338050	79	Naibasti	1151400	997880
35	Dashaawamedh	1776750	1539850	80	Onkleshwar	1524150	1320930
36	Kamalpura	2773050	2403310	81	Jangambari	1410600	1222520
37	Baghara	2604450	2257190	82	Paharpur	1482000	1284400
38	Sarsauli	2297700	1991340	83	Chetganj	1614000	1398800
39	Shivala	1450950	1257490	84	Khajuri	1167000	1011400
40	Pearikala	1449750	1256450	85	Kamchcha	1849200	1602640
41	Ramapura	1420050	1230710	86	Jolha	1758450	1523990
42	Rajmandir	1749900	1516580	87	Pisachmochan	1213800	1051960
43	Prahladghat	1756050	1521910	88	Ghasiyaritola	1176750	1019850
44	Garwasitola	1656600	1435720	89	Bhadaini	1535400	1330680
45	Kazipura	1569150	1359930	90	Nagwa	1292100	1119820

Source: Water demand estimated on the norm of CPHEEO (150 lpcd) and water supply estimated per capita by the Water Supply Department of Varanasi (130 lpcd).

Estimation of water demand in each year up to projected year

It can be observed that the water demand per day is gradually increasing decades after decades and the figures also indicate the average liter per capita per day of water supply within this region up to projected year (table 5).

The future quantities of water supply are closely linked to economic growth given un-changed water supply intensities in economic and human activities. Again the water supply is directly proportional to the rate of change of population. A mathematical calculation is the ultra-process beginnings with the estimation of future population based on the average increase in population of last two decades and then there is calculated the future amount of municipal water supply as following:

Future population (Pf) = Po (1+R/100) y

Po= Initial Population,

R= Percentage of growth rate = {(x1+x2)/2}/10, x1&x2 is the population increasing percentage of last two decades and

y = years.

The rate of increasing population varies decades after decades.

Table 5: The population and Water Supply Demand Projection of Varanasi up to Projected Year

No.	Year	Population	Population (Million)	Water Supply Demand (Million Liters/Day)	Water Supply Demand (Billion Liters/Day)
1	2011	1198492	1.2	328.8	0.32
2	2021	1457579	1.5	486.0	0.49
3	2031	1874945	1.9	752.4	0.76
4	2041	2376749	2.4	1168.8	1.17

Source: Calculated from the data of Jal Sansthan of Varanasi City

The average increasing rate is 29% for 2011-2021, 22% for 2021-2031and 23% for 2031-2041.

Future amount of Water Demand per day

Water Demand (Wd) = (Pf) x (Wc)

Pf = Predicted population, and

Wc = Water consumption (Million Liters/day).

The projections for urban water demand in 2041 were made by factoring expected growth in population and estimated water consumption per capita. The population data collected from census of India as per the report of technical group on population projections constituted by the national commission on population of the office of the Registrar general & Census commissioner of India. The population projection is calculated by the forecasting method. The population growth in Varanasi from 2011 to 2041 will have a growth of 21% in 30 years at a rate of 2.25 % per year. This growth rate is considered in the model from 2011 to 2041 to predict the water demand in the city. The data were collected from various municipalities as per the office records. It is estimated that the amount of drinking water requirement forecasted for 2021, 2031 and 2041 are 0.49, 0.76 and 1.17 Billion Liters per day respectively in Varanasi City. This data shows that with the increasing of population, the water demand also increases decade after decade. The population versus increase of water demand of year wise from 2011 to 2041 is obtained from the forecasting method shown above (fig.4).

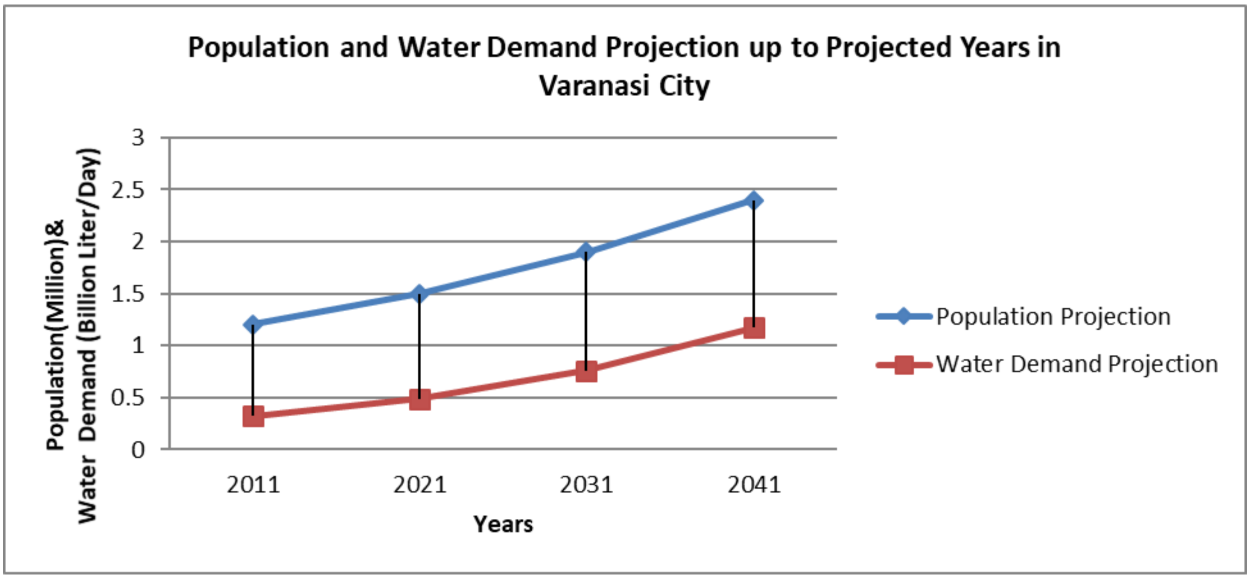

Figure 4: The population and water demand projection up to projected years in Varanasi City

Conclusion and suggestions

The future water demand is analysed by the forecasting method, illustrating the estimates of water demand from 2011 to 2041 which shows that if the growth of population and the growth of water demand rate increases per day it will be increasing proportionally. The supply of water in Varanasi city is going to be a big challenge in future. The rapid increase in population, depleting water resources and enhanced consumer needs are going to create a difficult situation.

The market oriented development is creating new needs in sectors like entertainment industry and tourism, construction industry, adapted new technologies pushing up water needs, more supply in shopping malls, and so on. Simultaneously, the alarming rise in pollution levels in surface water bodies and even in groundwater is added to this situation. The demand is likely to increase to 0.49, 0.76 and 1.17 Billion Liters per Day by 2021, 2031 and 2041 respectively. It is not an easy task to provide required amount of water to the city population as the flow and volume of water in Ganga river has considerably decreased. Besides the river water is polluted.

The water supply systems in Varanasi suffer from inadequate operations and maintenance. Lack of operations and maintenance is a major cause of distribution losses, and also affects the longevity of the system. Most households in the city do not receive adequate water. Often, the non-availability of water or water scarcity is cited as a reason. However, the major challenge in the city is the huge distribution losses which account for a significant amount of the non-revenue water in the city.

These losses are both physical due to decrepit pipes and lack of maintenance, and also monetary losses, due to incomplete metering and billing. The physical losses occur in three main ways: the leakages in the distribution mains, leakages at storage tanks, or leakages at service connection points. The present distribution system of water supply is more than 100 years old and hence prone to leakages. In some cases, the sewer lines cross the water supply lines posing a risk of contamination of the water supply. The preventive maintenance of the water supply lines through leak detection at regular intervals would prevent not only the contamination but also reduce the physical losses and line loss of pressure.

The frequent leakage and conflict points should be geo-detected and mapped for easy identification and prompt action. The water supply at the end consumer should also be monitored regularly and water testing kits should be distributed in the ward council for ease of the consumers and detection of possible contamination. The storage capacity is insufficient in the new extension areas of the city and there is no proper water system for slums. Therefore, an urgent need is felt for a comprehensive water policy for the city which is suitable and satisfactory to the growing needs of the citizens. The prevailing 'adhocism' in protecting, enhancing and conserving water needs to stop. In order to encourage the citizens, the municipal authority has to organize awareness programmes for the water supply management in the city.

References

Baumann, D.D., Boland, J.J. and Hanemann, M.W. (1997). Urban water demand management and planning (1st edition), McGraw Hill Professional, pp 1-350.

Chaves, H.M. and Alipaz, S. (2007). An integrated indicator based on basin hydrology, environment, life, and policy: the watershed sustainability index. Water Resources Management, 21(5), pp.883-895.

Cihakova, I. (2006). Expected development in the supply and distribution of drinking water in Czech Republic. Security of Water Supply Systems: from Source to Tap, pp.31-38. DOI: https://doi.org/10.1007/1-4020-4564-6_4

CPCB, A. (2008). Status of Water Supply, Waste Water Generation and Treatment in Class-I Cities & Class-II Towns of India, CPCB, Ministry of Environment & Forest, New Delhi.

Chaurasia, J., Rai, P.K. and Singh, A.K. (2013). Physico-Chemical Status of Groundwater Near Varuna River in Varanasi City, INDIA, International Journal of Environmental Sciences (Integrated Publication Association), Vol.3 (6), pp 2114-2121.

Dubey, K.K. (1976). Use and Misuse of land in'KAVAL'Towns of Uttar Pradesh. NGSI, Vol.15, pp.43-46.

Giertz, S., Hiepe, C., Höllermann, B. and Diekkrüger, B. (2010). Impacts of global change on water resources and soil degradation in Benin. Impacts of global change on the hydrological cycle in West and Northwest Africa (edited. book), Springer, pp.484. DOI 10.1007/ 978-3-642-12957-5.

Government of India. (1999). Water Resources Development Plan of India: Policy and Issues. National Commission for Integrated Water Resources Development Plan. Ministry of Water Resources, New Delhi.

Iglesias, A. (2002). Climate Changes in the Mediterranean: Physical aspects and effects on agriculture. Mediterranean Climate. Springer. New York.

McIntosh, A. (2003). Asian water supplies: reaching the urban poor. Asian Development Bank, IWA Publishing. ISBN 971-561-380-2.

Mohan, K. Shrivastava, A. & Rai, P.K. (2011). Ground Water in the City of Varanasi, India: Present Status and Prospects, Quaestiones Geographicae, Vol. 30, No. 3, 47-60. DOI: 10.2478/v10117-011-0026-9.

Pradhan, P. (2003). Water Demand Forecast and Management Modeling: An Application to Kathmandu Valley. Nepal. Unpublished master's thesis, Asian Institute of Technology, Bangkok, Thailand, p.87.

Radhakrishna, B.P. (2008). Water Supply and Sanitation in the Indian Context. Geological Society of India, 71(5), pp.605-610.

Rai P.K. & Nathawat M.S. (2013). GIS in Health Care Planning: A Case Study from India , Forum Geographic Journal (Romania), 12 (1), 152-163. Available at: http://dx.doi.org/10.5775/fg.2067-4635.2013.180.d.

Rai, P.K., and Mohan, K. (2014). Remote Sensing Data & GIS for Flood Risk Zonation Mapping in

Varanasi District, Forum Geographic Journal (Romania), Vol. 13 (1), 25-33. Available at DOI: http://dx.doi.org/10.5775/fg.2067-4635.2014.041.i.
Singh, J. and Kumra, V. (1997). Ganga Action Plan and River Water Quality. Geography and Environment: Local issues, 3, p.145.
Udovyk, O. (2006). GIS for Integrated Water Resources. Integrated Urban Water Resources Management, Springer, Dordrecht, pp.35-42. https://doi.org/10.1007/1-4020-4685-5_4.
Van Engelen, J.G.M., Hakkinen, P.J., Money, C., Rikken, M.G.J. and Vermeire, T.G. (2007). Human Exposure Assessement. In Risk Assessment of Chemicals, pp.195-226. Springer, Dordrecht. DOI: https://doi.org/10.1007/978-1-4020-6102-8_5.
Zérah, M.H. (2000). Water, unreliable supply in Delhi. Manohar Publishers. ISBN: 81-7304-328-0.

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Indicators for evaluating the role of green infrastructures in sustainable urban development in Romania

Mihai Răzvan NIȚĂ[1*], Maria PĂTROESCU[1], Denisa Lavinia BADIU[1], Athanasios Alexandru GAVRILIDIS[1], Marga-Elena AVRAM[2]

[1] Centre for Environmental Research and Impact Studies, University of Bucharest, Romania
[2] Simion Mehedinţi Doctoral School, Faculty of Geography, University of Bucharest, Romania
* *Corresponding author*, nitamihairazvan@yahoo.com

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Abstract

Urban green infrastructures are now considered key elements in improving residents' quality of life and creating an appropriate framework for the development of sustainable cities. One of the most efficient method to evaluate the state and performance of urban green infrastructure is using different types of indicators. The indicators for evaluating the benefits, ecosystem services and the role of green infrastructures for the process of sustainable development represent important tools for decision and policy makers. Indicators provide information that can be easily interpreted by decision and policy makers and they facilitate the process of planning, monitoring and evaluation of green infrastructure in urban areas. The focus of our study is to establish which indicators are used for underlining the structural and functional diversity of urban green infrastructures. This paper aims to highlight the indicators and indices being used in Romanian urban areas for measuring their sustainability that include green infrastructures, in the wider understanding of the concept. Throughout the paper, different examples of indicators and indices are provided, emphasizing that by using the proper set of indicators and indices, city authorities can tag a sustainable development label for certain areas. However, an unbiased assessment using some sets of indicators and indices are not always providing unbiased or realistic outcomes.

Keywords: *indicators, urban green infrastructures, sustainability*

Rezumat. Indicatori de evaluare a rolului infrastructurilor verzi în dezvoltarea urbană durabilă în România

Infrastructurile verzi urbane sunt considerate elemente cheie pentru îmbunătățirea calității vieții rezidenților și crearea unui cadru adecvat pentru dezvoltarea orașelor durabile. Una dintre cele mai eficiente metode de evaluare a stării și performanței infrastructurilor verzi urbane constă în utilizarea a diferite tipuri de indicatori. Indicatorii de evaluare a beneficiilor, serviciilor ecosistemice și a rolului infrastructurilor verzi în procesul de dezvoltare durabilă reprezintă instrumente importante pentru factorii de decizie și cei politici. Indicatorii oferă informații ce pot fi ușor interpretate de către decidenții politici and facilitează procesul de planificare, monitorizare și evaluare a infrastructurilor verzi urbane. Studiul nostru se concentrează pe stabilirea unor indicatori ce ar putea fi folosiți pentru a evidenția diversitatea structurală și funcțională a infrastructurilor verzi urbane. Scopul acestei lucrări este de a sublinia indicii și indicatorii utilizați în arealele urbane din România pentru a cuantifica sustenabilitatea infrastructurilor verzi, pentru o profundă înțelegere a acestui concept. Pe parcursul lucrării sunt propuși o serie de indicatori, subliniind faptul că, prin utilizarea setului corespunzător de indici, autoritățile locale pot eticheta un anumit areal ca având o dezvoltare urbană durabilă. Cu toate acestea, o evaluare obiectivă pe baza unui anumit set de indicatori, nu oferă întotdeauna rezultate realiste.

Cuvinte-cheie: *indicatori, infrastructuri verzi urbane, durabilitate*

Introduction

Urban settlements are confronted with a series of environmental, economic and social problems affecting both their structure and functions (Ioja et al., 2014). New challenges such as globalization, emigrant crises or environmental changes have determined international organizations promoting policies and strategies (Habitat I and II, Local Agenda 21, European Urban Charter, Millennium Declaration, Metrex, etc.) with the objective of achieving a sustainable development of cities (Schäffler&Swilling, 2013).

Sustainable urban planning aims at approaching problems in a holistic manner by considering specific scale issues (Norton et al., 2015), integrating the vision of policy makers (Vandermeulen et al., 2011) or selecting the right solution for development (Govindarajulu, 2014). The integration of all aspects in urban planning requires a more strategic, interdisciplinary and socially-inclusive process that increasingly uses green infrastructures in the decision-making process (DG Environment, 2012) as a way to contribute to achieving sustainability and resilience goals (Church, 2015).

A sustainable city is a challenge of present society (Ferrer et al., 2018) as it imposes a new approach in organizing the urban space and connecting urban functions, a demanding task for old urban areas passing throughout history, through successive and sometimes antithetic patterns of planning. Direct effects are present in the transformation of traditional grey infrastructures into modern and sustainable ones (Niță et al., 2018) following the objectives of sustainable development. On the other hand, the race for sustainability sometimes reduces or eliminates local differences in the structural and functional diversity in sectors of the city and, nonetheless, as sustainability is a catalyst for globalization, cities aiming in achieving this goal are likely to lose their authenticity due to the fact that urban areas no longer address to local community but they address to a globalized world.

The use of green infrastructures in urban planning has increased as it is capable of contributing to a wide variety of policy objectives and goals in a sustainable manner (Bianchini&Hewage, 2012). Green infrastructures represent an instrument of achieving these goals, with their ecological, social and economic benefits being beyond doubt (Tzoulas&James, 2010). Planning with green infrastructures calls for different kinds of information compared to classical processes (Giordano, 2012), especially assessments considering their multifunctionality and the achievement of environmental, economic and social objectives (DG Environment, 2012).

Green infrastructure was originated as a concept in the 19th century in the search of connecting both parks and other urban areas for the benefits of population and also the conservation and connection of natural protected areas for the benefits of biodiversity (Benedict&McMahon, 2006). Urban green infrastructures are represented by a network consisting of: central areas (parks, urban forests, cemeteries, sport facilities), corridors (street alignments, water bodies, protection patches) and stepping stones (compact areas of small sizes – institutional gardens, residential green spaces) (Niță, 2016).

Urban green infrastructures are a concept with a multitude of visions (Newell et al., 2013) but represent in the broadest definition connected networks of multifunctional areas supporting ecologic and social processes (Iojă et al., 2014). Green infrastructures exhibit connectivity and multifunctionality as underlying features, covering a range of varying elements. Green infrastructures are defined by a series of characteristics that allow their evaluation: critical mass (minimal dimension of an element that can be considered as green infrastructure), benefits provided to the population, multifunctionality (the variety of their functions for society and nature also), the replacement of a traditional infrastructure and the degree of anthropic involvement in their maintenance (IEEP, 2011).

The main aim of the present paper is to establish which indicators are used for underlining the structural and functional diversity of urban green infrastructures. The main objectives are (i) establishing typologies of indicators according to aspects of urban green infrastructures they assess and (ii) evaluating the current situation of indicators used in planning documents for evaluating urban green infrastructures.

Typologies of indicators for assessing urban green infrastructures

Green infrastructure indicators can be found in a variety of forms: from simple qualitative or quantitative approaches to complex models accounting for indirect benefits or co-benefits. It is always useful to frame indicators into typologies, allowing both scientists and public administrations to select the most relevant ones.

1. Descriptive and performance indicators

One of the first methods of delineating indicators used in evaluating the contribution of urban green infrastructures to the sustainability of the city is that with two simple categories: descriptive and performance. This simple delineation, used by other studies (de Groot, Alkemade et al., 2010) is very useful in connecting indicators with their contribution to sustainability: state indicators concentrate on the number or surface (characterizing multiple elements of urban green infrastructures), while performance indicators determine the contribution of those elements to the general objectives of the city (Fig. 1).

It is notable that state indicators are easier to calculate and interpret the results, while performance indicators require both good data sources but also in-depth understanding of the mechanisms controlling environmental, social and economic processes at city-level. Both descriptive and performance indicators can be calculated at various spatial scales.

2. Indicators of benefits

A second approach in delineating indicators is in categories according to the specific benefits which we are trying to achieving from urban green infrastructures. Given their multifunctionality, this is challenging, as most of the times green elements provide multiple benefits and even co-benefits at city level (Raymond et al., 2017), but most of the authors delineate indicators on three main categories of benefits: ecological, social and economic.

Ecological benefits regard improving air quality through carbon sequestration and filtration of pollutants, reducing erosion due to rainwater or diminishing the negative effects of noise pollution (Badiu et al., 2016). Ecological indicators can be represented therefore by: Amounts of sequestered Carbon (kg/ha/year), Pollutants (PM10 and PM2.5, SO_2, NO_2, CO, O_3, CO_2) retained by trees or other vegetation (tons/ha/year), Changes in air temperature in vegetated surfaces (°C), Water retention in vegetation and soil (tons/sqkm) or Percent of permeable surfaces (% of constructed spaces).

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While some of these indicators are easy to calculate and represent (Fig. 2 – percent of permeable surfaces in urban areas) for most of the ecological indicators intensive studies are required, especially given the high diversity of species and processes in urban green infrastructures and results are not always easily understood by various stakeholders.

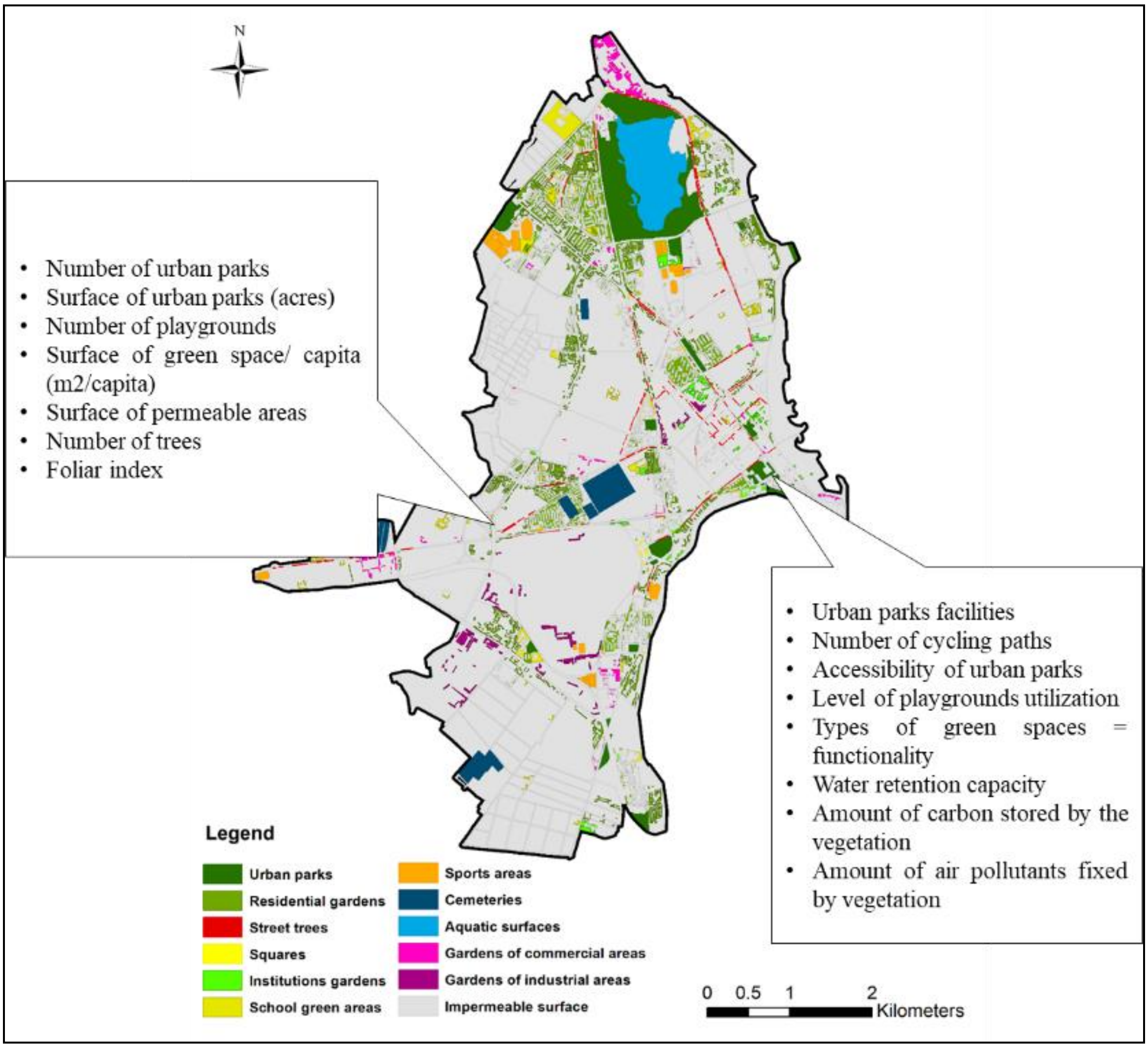

Fig. 1: Examples of state and performance indicators of urban green infrastructures in Constanța, Romania

Social benefits cover a wide range of aspects from the aesthetic improvement of urban landscape to the provision of recreation spaces, providing opportunities for socialization, areas for different sports and improving the general health state of the population. In respect, social and cultural indicators are represented by: number of public recreation sites (no.), accessibility to urban green infrastructures (no. of inhabitants situated at a minimum distances), number and magnitude of events organized in urban green infrastructures (no. of participants), frequencies of visits (no. or duration).

If accessibility (Fig. 3) and other descriptive social indicators are relatively easy to calculate especially using GIS techniques, for other indicators such as social cohesion, health improvement or opportunities for socialization, their calculation is difficult due to data deficiencies and the lack of a clear connection between the urban green infrastructure and its benefits.

Economic benefits include elements such as real-estate changes, reducing energy consumption or providing direct economic incomes from activities associated with elements of urban green infrastructures. Economic indicators can be represented by the real-estate value of buildings in the proximity (euro/sqm), monetary value of medicinal species (euro), reduction of medical expenses (euro/year), energy consumption for air conditioning (euro/year) or the biomass capacity in urban areas (Fig. 4).

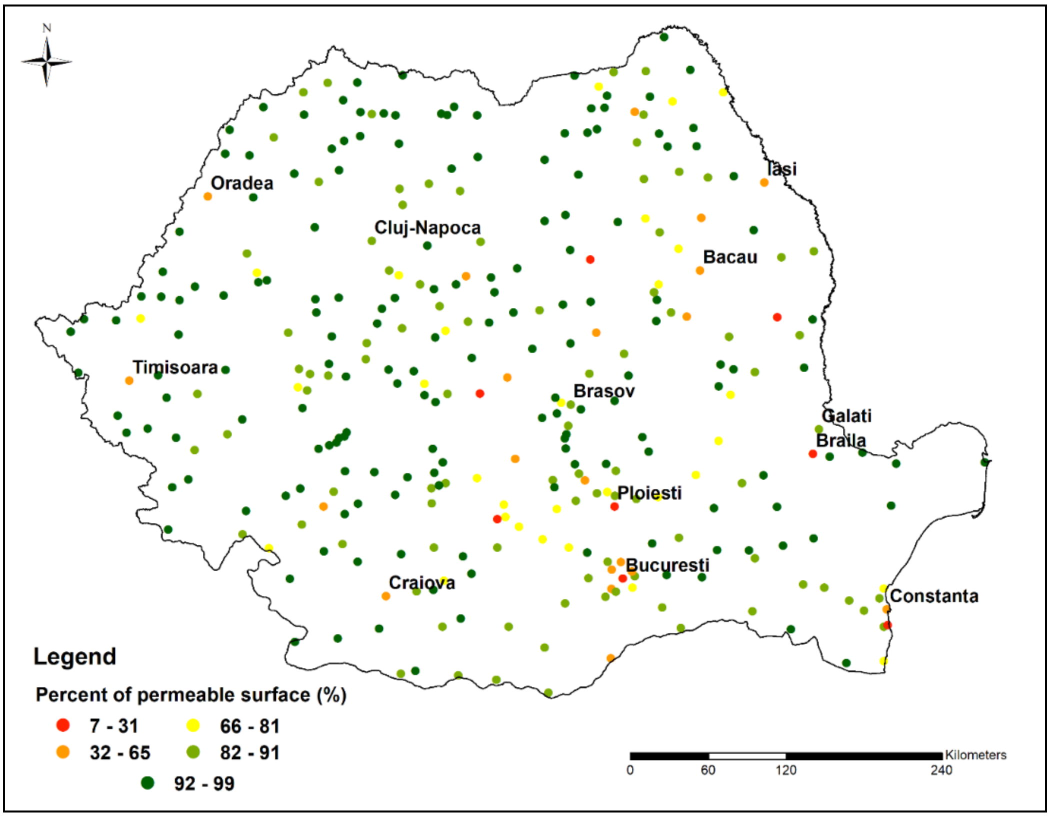

Fig. 2: Ecological and descriptive indicator - permeable surface in urban areas from Romania (after Niță, Onose et al., 2017)

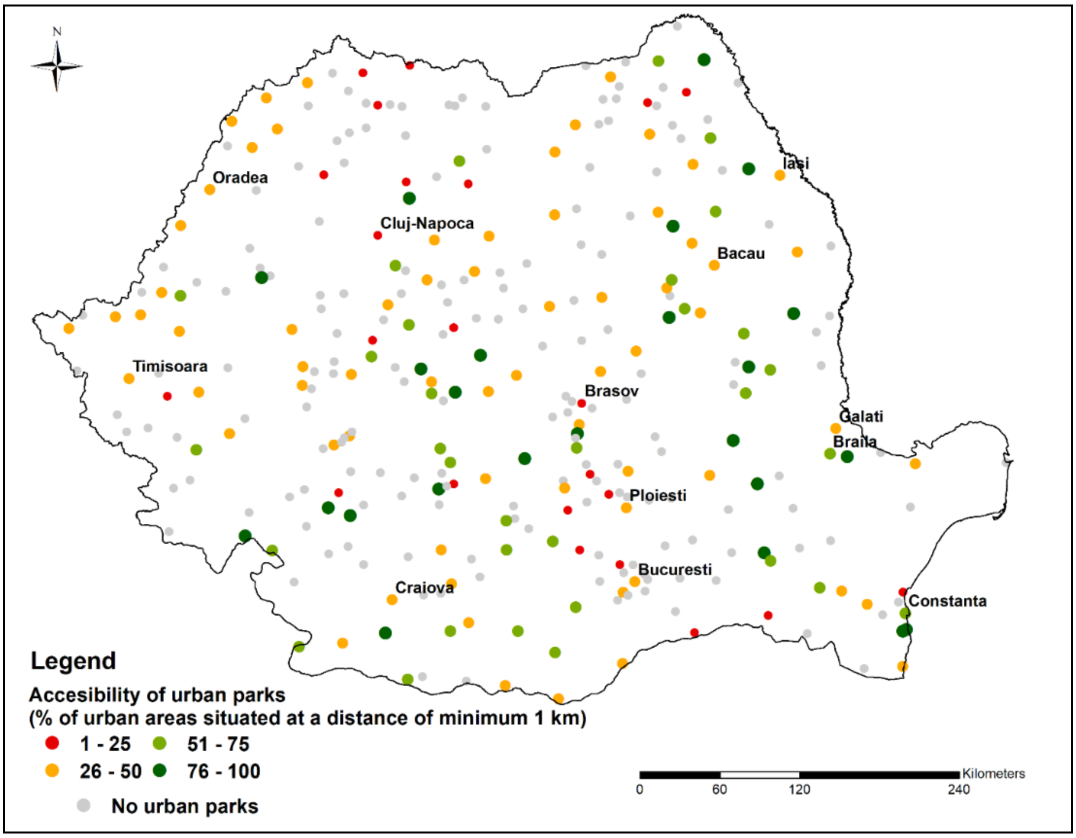

Fig. 3: Socio-cultural and performance indicator - accessibility of urban parks in Romanian cities (after Niță, Onose et al., 2017)

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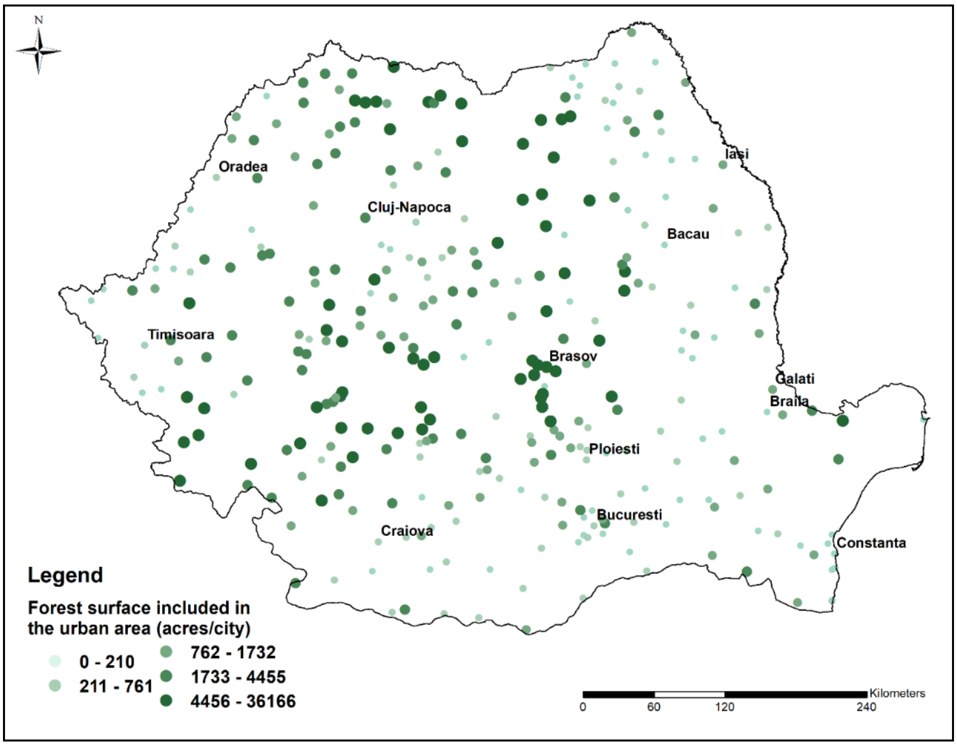

Fig. 4: Economic and descriptive indicator - biomass capacity in urban areas (after Niță, Onose et al., 2017)

Indicators evaluating the benefits of urban green infrastructures represent useful instruments for decision makers and in the same time facilitate the communication between experts and non-experts. Their separation into ecological, social and economic indicators makes it easier to relate them to the sustainable development goals as established at city level (Gavrilidis et al., 2017).

3. Indicators for ecosystem services

One of the most recent approaches regarding the urban green infrastructures benefits is linked by the quantification of urban ecosystem services. Through the evaluation of ecosystem services provided by urban green infrastructure, a tangible value is attributed to these benefits, which is more efficient to manage by the decisional authorities. For the evaluation of ecosystem services in urban environments, the European Commission has published the report Mapping and assessment of urban ecosystems and their services (Rocha et al., 2015) which presents a series of indicators used for quantifying the provision, regulatory and cultural services.

According to the classification of ecosystem services at urban level, they are indicators for the evaluation of urban green infrastructures

(i) provision services - biomass quantity of big and mature trees per forest surface (t/ha), number of species which present medical value, the harvested quantity (no./ha, euro/ha (kg or t)/ha) or forest cover (%);

(ii) regulatory and support services - quantity of carbon sequestrated in the trees canopy (t/ha), the capacity of water storage in vegetation and soil (t/sqkm), reduction of green gas emissions (%), trees shading area (urban climate regulation) (sqm), trees cooling potential (t C/ha) or ecological prints (tCO2);

(iii) cultural services - suitable space for open air cultural activities (m2), recreational potential (between 0 and 1), spatial distribution of runners and bikers (number of runners and bikers/ hour/km), kids playgrounds surface (m2).

Most frequently such indicators are interlinked, as urban green infrastructures provide a wide range of ecosystem services in the same time (Fig. 5), increasing their potential for improving the sustainability of a city.

Presence of indicators in planning documents

Previous studies have analyzed the presence of green infrastructures in planning and strategic documents at urban level (Niță et al., 2017) and demonstrated that despite their importance there are frequently seen as marginal spaces of urban development. Planning documents contain numerous indicators for assessing elements of urban green infrastructures: temporal dynamic of surfaces occupied by urban green infrastructures, newly established surfaces of urban green infrastructures, forest surfaces, managed green surfaces, distance covered by street alignments, number of green areas such as playgrounds, surface of sport facilities, surfaces of green areas per capita.

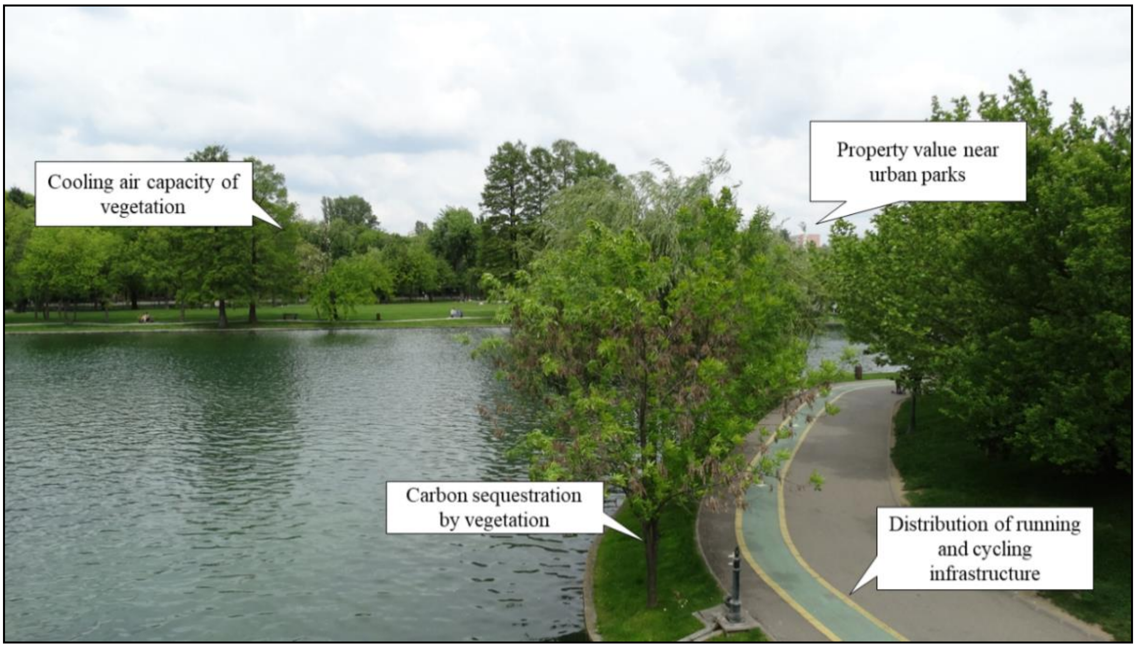

Fig. 5: The variety of ecosystem services delivered by an urban park in Bucharest

It is obvious that most of the indicators are simple descriptive ones, indicating only the state of green at city level. For a better connection between the urban green infrastructures and the sustainability of cities one should also include performance indicators assessing the ecologic, economic and social benefits of urban green. These indicators should be organically integrated both in public policies but also in legislation at various geographical scales (Badiu et al., 2016).

Public administration should seek to firstly create a database of urban green infrastructures in accordance with the reality which could assist in the calculation of indicators and further down to achieving the sustainability goals. In addition, besides indicators which are mandatory to calculate at city level, administrations should develop complementary indicators distributed among all categories, considering in equal manner the social, economic and environmental components, and being part of an integrated system of urban monitoring.

Green infrastructures should have their specific place in the urban ecosystems, in a complementary or often hybrid relation with other infrastructures. The change in the population consumption models will determined profound structural and functional changes in the distribution of urban green infrastructures, aimed at integrating spaces such as playgrounds, areas for pets or area designated for concerts or markets. In their search for contributing to the sustainability of the cities, urban green infrastructures could be developed on abandoned lands (including those with water or soil challenges), open spaces inside the built-up areas (brown-fields) or alternative locations (green roofs or walls).

Conclusion

The article presents the main categories of indicators assessing the contribution of urban green infrastructures to achieve urban sustainability and presented three main typologies: descriptive and state indicators, indicators assessing benefits and those focused on the evaluation of ecosystem services. We found that currently indicators used in planning documents for evaluating urban green infrastructures are mostly simple descriptive indicators. Our results emphasize the need to complementary use different types of indicators in analyses, rather than just descriptive ones and also push for the integration of indicators' results in the process of urban planning.

References

Badiu, D.L., Iojă, C.I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M.R., Grădinaru, S.R., Hossu, C.A., Onose, D. A. (2016). Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study, *Ecological Indicators*, 70: 53-66.

Benedict, M.A., McMahon, E.T. (2006). *Green Infrastructure. Linking landscapes and communities*, Island Press.

Bianchini, F., Hewage, K. (2012). Probabilistic social cost-benefit analysis for green roofs: A lifecycle approach, *Building and Environment*, 58: 152-162.

Church, S.P. (2015). Exploring Green Streets and rain gardens as instances of small scale nature and environmental learning tools, *Landscape and Urban Planning*, 134: 229-240.

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, *Ecological Complexity*, 7(3): 260-272.

DG Environment (2012). *The Multifunctionality of Green Infrastructure. Science for Environment Policy*.

Ferrer, A.L.C., Thomé, A.M.T., Scavarda, A.J. (2018). Sustainable urban infrastructure: A review. *Resources, Conservation and Recycling,* 128: 360-372.

Gavrilidis, A.A., Niță, M.R., Onose, D.A., Badiu, D.L., Năstase, I.I. (2017). Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure, *Ecological Indicators*, 10.1016/j.ecolind.2017.10.054.

Giordano, T. (2012). Adaptive planning for climate resilient long-lived infrastructures. *Utilities Policy*, 23: 80-89.

Govindarajulu, D. (2014). Urban green space planning for climate adaptation in Indian cities. *Urban Climate*, 10: 35-41.

IEEP (2011). Green infrastructure implementation and efficiency. Final report. Institute for European Environmental Policy.

Iojă, C.I., Grădinaru, S R., Onose, D.A., Vânău, G.O., Tudor, A.C. (2014). The potential of school green areas to improve urban green connectivity and multifunctionality, *Urban Forestry&Urban Greening*, 13(4): 704-713.

Ioja, I.C., Niță, M.R., Vânău, G.O., Onose, D.A., Gavrilidis, A.A. (2014). Using multi-criteria analysis for the identification of spatial land-use conflicts in the Bucharest Metropolitan Area, *Ecological Indicators*, 42: 112-121.

Newell, J.P., Seymour, M., Yee, T., Renteria, J., Longcore, T., Wolch, J.R., Shishkovsky, A. (2013). Green Alley Programs: Planning for a sustainable urban infrastructure?, *Cities*, 31: 144-155.

Niță, M.-R., Anghel, A.-M., Bănescu, C., Munteanu, A.M., Pesamosca, S.-S., Zețu, M., Popa, A.M. (2017). Are Romanian urban strategies planning for green?. *European Planning Studies*: 1-16.

Niță, M.R. (2016). *Infrastructuri verzi-o abordare geografică*, Editura Etnologică, București.

Niță, M.R., Badiu, D.L., Onose, D.A., Gavrilidis, A.A., Grădinaru, S.R., Năstase, I.I., Lafortezza, R. (2018). Using local knowledge and sustainable transport to promote a greener city: The case of Bucharest, Romania, *Environmental Research*, 160: 331-338.

Niță, M.R., Onose, D.A., Gavrilidis, A.A., Badiu, D.L., Năstase, I.I. (2017). *Infrastructuri verzi pentru o planificare urbană durabilă*, Ed. Ars Docendi, București.

Norton, B.A., Coutts, A.M., Livesley, S.J., Harris, R.J., Hunter, A.M., Williams, N.S.G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes, *Landscape and Urban Planning*, 134: 127-138.

Raymond, C.M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M.R., Geneletti, D., Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas., *Environmental Science&Policy*, 77: 15-24.

Rocha, S.M., Zulian, G., Maes, J., Thijssen, M. (2015). *Mapping and assessment of urban ecosystems and their services*, Joint Research Centre.

Schäffler, A., Swilling, M. (2013). Valuing green infrastructure in an urban environment under pressure — The Johannesburg case, *Ecological Economics*, 86: 246-257.

Tzoulas, K., James, P. (2010). Peoples' use of, and concerns about, green space networks: A case study of Birchwood, Warrington New Town, UK, *Urban Forestry&Urban Greening*, 9(2): 121-128.

Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., Gellynck, X. (2011). The use of economic valuation to create public support for green infrastructure investments in urban areas, *Landscape and Urban Planning*, 103(2): 198-206.

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Using GIS methods to analyze spatial characteristics of urban transportation system in Craiova city

Cristiana VÎLCEA[1,*], Sorin AVRAM[1], Claudia FLORESCU[2]

[1] Faculty of Science, Department of Geography, University of Craiova, Romania
[2] Faculty of Geography, University of Bucharest, Romania
* *Corresponding author*: cristiana_oana@yahoo.com

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Abstract

In a world of technology, where the increasing urbanization tries to cope between sprawl and the need to actively manage a sustainable land and resources use, transportation remains among the main challenges for physically active cities like Craiova. The city is the major growth pole located in South-West Oltenia, which connects most of the settlements in the region (both rural or urban) economically and socially. Thus, the transportation system represents the key element in the relation between time and place in this metropolitan area in a continuous development process. While the city expands, the transportation network, inherited from the past, suffers a slower transformation, despite the increasing demand for mobility coming from both passengers and freights. The spatial analysis of new residential areas emerged in the continuous process of urban expansion indicate an additional pressure on the existing road infrastructure and which intensifies especially during peak hours on the access routes to the city and city center. Starting from the analysis of the spatial structure and distribution of the pre-existent rural structure, the present study tries to emphasize the need for an innovative and integrated infrastructure that should connect at its best space, services and people in terms of speed, capacity and cost efficiency. First, using the GIS mapping methods, the authors present the spatial distribution of the transport infrastructure that is correlated with population density and land use, also analyzing the areas with high density of jobs and elements of the urban landscape that may generate attractivity. A special attention is paid to the urban form - street pattern relation, exemplified by case studies in problematic intersections of Craiova city. All these factors are important in order to establish the present capacity of the urban transportation system during peak hours, and what are the main deficiency of the transport system: traffic jams, insufficient parking places, need of new connections in public transportation. The results of the research may be used to improve passenger transport inside the city of Craiova and may also suggest some solutions that mitigate for the introduction of new concepts like car sharing, electric public transportation, hybrid vehicles or new alterna-tives for peoples' movement.

Keywords: *urban transport, connectivity, passengers and freight movement, urban land use*

Rezumat. Utilizarea metodelor GIS pentru analiza caracteristicilor spațiale ale sistemului de transport urban în orașul Craiova

Într-o lume a tehnologiei, în care creșterea urbaă încearcă să facă față extinderii și necesității de a gestiona în mod activ o utilizare durabilă a terenurilor și a resurselor, transportul rămâne printre principalele provocări pentru orașele fizic active precum Craiova. Acesta este cel mai important pol de creștere din sud-vestul Olteniei, care conectează majoritatea așezărilor din regiune (atât rurale, cât și urbane) din punct de vedere economic și social. Astfel, sistemul de transport reprezintă elementul cheie în relația dintre timp și loc în această zonă metropolitană într-un proces de dezvoltare continuă. În timp ce orașul se extinde, rețeaua de transport, moștenită din trecut, suferă o transformare mai lentă, în ciuda creșterii cererii de mobilitate provenind atât din partea pasagerilor, cât și a transportului de mărfuri. Analiza spațială a zonelor rezidențiale noi apărute în procesul continuu de expansiune urbană indică o presiune suplimentară asupra infrastructurii rutiere existente și care se intensifică, în special în timpul orelor de vârf, pe rutele de acces către oraș și în centrul acestuia. Pornind de la analiza structurii spațiale și a distribuției structurii rurale preexistente, studiul de față încearcă să sublinieze necesitatea unei infrastructuri inovatoare și integrate care să se conecteze la cel mai bine spațiul, serviciile și persoanele în ceea ce privește viteza, capacitatea și eficiența costurilor. În primul rând, folosind metodele de cartografiere GIS, autorii prezintă distribuția spațială a infrastructurii de transport corelată cu densitatea populației și utilizarea terenurilor, analizând de asemenea zonele cu densitate mare a locurilor de muncă și elemente ale peisajului urban care pot genera atractivitate. O atenție deosebită este acordată relației dintre structura urbană și a tramei stradale, exemplificată prin studii de caz în intersecții problematice din orașul Craiova. Toți acești factori sunt importanți pentru a stabili capacitatea actuală a sistemului de transport urban în timpul orelor de vârf și care sunt principalele deficiențe ale sistemului de transport: blocaje de trafic, locuri de parcare insuficiente, nevoia de legături noi în transportul public. Rezultatele cercetării pot fi utilizate pentru a îmbunătăți transportul de călători în interiorul orașului Craiova și pot sugera, de asemenea, unele soluții care promovează introducerea conceptelor de partajare a autovehiculelor, transportul public electric, vehiculele hibride sau alternative noi pentru deplasarea oamenilor.

Cuvinte-cheie: *transport urban, conexiune, transportul persoanelor și al mărfurilor, utilizarea urbană a terenurilor*

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Introduction

The rapid urban expansion during the last decade caused by the socio-economic growth of modern society based on technology has major repercussions on urban mobility (Gonzalez M. et al, 2008). Besides the environmental impact, most urban centers face problems concerning the mobility, the transport infrastructure being overcome and causing frequent traffic jams (Jingyuan Wang et al., 2014), which reduce the efficiency of car transport by increasing the time travel for relative short distances, augmenting the fuel consume and producing air pollution (Belik, V. et al., 2011; Pengjun Zhao, 2010).

Nowadays, mobility is essential for the economic development to take place, both locally and regionally, influencing the people wealth fare and that is why policy makers must focus of transport efficiency and sustainability. Although the road density is high, for most cities it became insufficient and road extension is not a viable solution anymore, especially inside the cities, mainly because of urban land use (high price land, historical centers closed for traffic circulation). Also, extending the road infrastructure and encouraging urban mobility based on motorized transportation generates a vicious circle which will cause the exponential increase of the number of cars (Gutiérrez J & García-Palomares J.-C., 2008).

In EU, most cities face problems regarding the urban transport, which generates not only deficiencies in the movement of people and freights, but also a high level of pollution. In this respect, it was decided to find viable solutions by discouraging individual car movement and promoting the collective transportation or by developing non-motorized transportation means. Thus, all big European cities must have a sustainable urban mobility plan, the main objective of which is to improve accessibility of urban areas and providing high-quality and sustainable mobility and transport to, through and within the urban area. It regards the needs of the "functioning city" and its hinterland rather than a municipal administrative region and contributes to a better overall performance of the trans-European transport network and the Europe's transport system as a whole (CE, 2013).

Although Craiova experiences a relatively recent urban sprawl, the city deals with the increase of car number and the intensification of road traffic in both the city center and urban fringe. So, the car use increased, same as the distances covers daily, with the mention that most of the times the time and distance relation is not optimal. (Banister, D., 2008). Because of this ratio, the transportation costs increase for all type of transport (Mir Shabbar Ali et al., 2014). As many other big cities, Craiova develops a spatial structure based on the individual car transportation.

Study area

Craiova is one of the seven urban growth poles in Romania (along Brașov, Cluj-Napoca, Constanta, Iași, Ploiești and Timișoara), being the largest city in South West Ol-tenia Development Region. In the given context, Craiova municipality polarizes most of the economic activity in the region, exceeding the limits of its metropolitan area due to the socio-economic connections established with the rest of the nearby urban and rural set-tlements. There is a strong connection between the transport infrastructure and the urban influencing area of Craiova, creating a functional metropolitan area slightly different from the one officialy established by the Law 215/2001, Law 351/2001, Law 350/2001, Govern-ment Ordinance no 26/2000, Law 246/2005 and based on the Decission of the Local Council of Craiova no 297/27.11.2008 (fig. 1).

The metropolitan area of Craiova holds 54% of the population within Dolj county (75% of the population in the metropolitan area lives in Craiova). The population of 304,089 inhabitants (INS, 2017) is unevenly distributed on the urban area of the city (105.39 sq km out of which 81.41 sq km urban area), with a density of 3,310 inhabitants/sqkm (Table 1). The metropolitan area represents 20% of the total surface of Dolj county (fig. 1). The urbanization rate in the metropolitan area is high, as demographically, 82% of the popula-tion is concentrated in three urban centers and only18% lives in the rural area.

Table 1: Table 1 – Spatial and demographic changes in the urbanized area of Craiova

	1992	**2011**	**Change**
Population	307,077	311,909	1.55%
Urbanized area (sq km)	58,80	81,41	27.77%
Population density (pers/ sq km)	5,222	3,831	- 36.31%

Source: calculations made by the author using statistical data

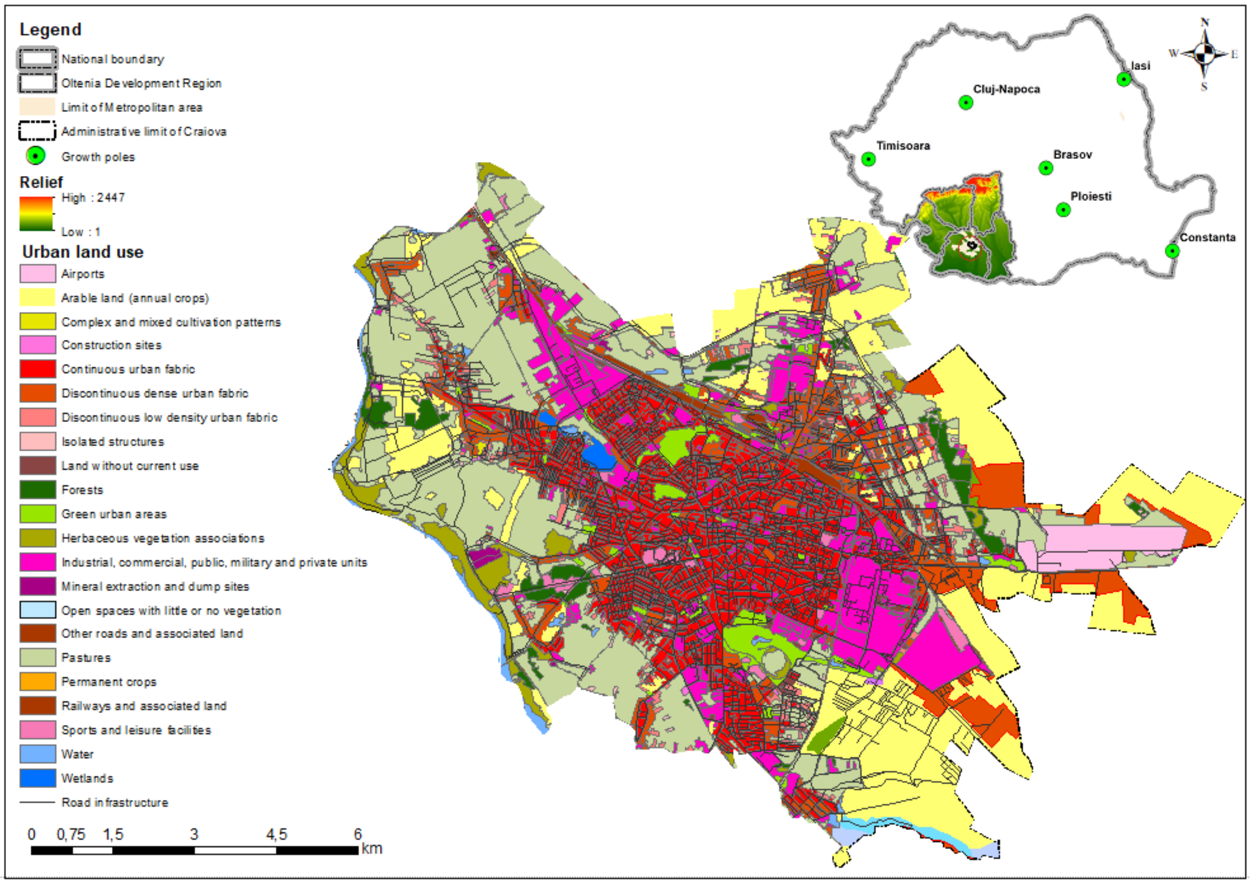

Fig. 1: Location and limits of the study area

Data and Methods

Several specific tools have been used in ArcGIS 10.5 for the processing and geospatial representation of statistical data and raw information. The initial mapping stage began with the collection of available data and the creation of the geospatial database, using both vector and raster data to create a spatial database. For the use of data from different sources in later integrated analyses, they were spatially homogenized using GIS applications that provide specially designed data management tools for defining or transforming projections, as well as georeferencing. As a toolbox, GIS allowed us to perform spatial analysis using geoprocessing functions such as map overlay, connectivity measurement, and buffering. There were also used the Spatial analyst functions and modelling for statistical and land use transport analysis.

The study focuses on analysing the access and coverage of public transport in relation to residential, commercial and job connected areas. The analysis of the coverage to a public transportation line started from the density of transport lines and exiting stations. Two areas of interest have been established for analysis by applying a 200 meters and a 500 meters buffer around the transport lines using the Euclidean (straight line) distance. The land use categories within the buffer area, mapped on SPOT 5 images and 1:5,000 orthophotoplans, were reclassified in three categories: residential (including new residential area), commercial (including commercial areas, industrial and educational) and other (including green areas, services and other). The public transport, serving especially these land use categories, is analysed with an emphasis on the residential areas because of their rapid development during the last period in Craiova. The overlapping and intersection between the sections determined by the two buffers and layers containing information about the land use, functional areas and population density (processed statistical data) were performed in order to determine the residential surfaces covered by the public transport. The sums of the land cover categories have been converted in percentages related to the total area used subsequently to compare the two situations resulted.

In order to identify urban traffic issues on some road sections and in critical points, the second part of the study focuses on collecting and processing the data needed to calculate the speed and travel time on several streets. In this respect, we selected several intersections and four road sections (each being one km long), located on four of the most circulated major road arteries, for which field observations and measurements were made during a week period. Data regarding the road traffic came from field observations made during a week in three daytime periods: 8:00 – 9:00 a.m, 12:00 – 13:00 p.m. and 17:00 – 19:00 p.m. Also, road traffic data for Craiova and for the same time intervals was analysed; it was offered live by Google Maps (http://www.mapparade.com/map-of-craiova-in_ro-mcza). All information had been processed and data resulted were used to calculate the mean travel speed, in one direction, toward the city center (U.S. Department of Transportation, 2007). The final results were spatially modelled in the GIS environment.

Discussion

In order to understand the traffic problems, the authors pay a special attention to the interaction between transportation and urban land use, which is responsible for the dayly mobility trends in Craiova (worked-based obligatory movements, like commuting or professional ones, and voluntary movements connected to commercial or leisure activities personal or tourists' movements) (Rodrigue J.-P., 2017). There is a strong link between the activities carried out depending on transport and its attractiveness, which influence the urban land use, the latter generating the activities. Staring from the circular relation between the determinants of this equation, there were identified three areas with different features of mobility and transport modalities (fig. 2):

- *The historical city center* in which the pedestrian area prevails, and the car access is re-stricted to locals (access by barriers) and to special services and supply, regulated by a strict hour interval. Nearby there are public transport terminals and connection stations, but there are no bike lanes and no bike rental centers. The activities specific to CBD dominate this area, where a number of public institutions (City Hall, Prefec-ture) and prestigious education establishments (University, 3 high schools), as well as numerous tourist attrac-tions are located (within a radius of 0.5-1 km). This area is characterized by a high density of urban constructions and a high concentration of finance activities.

- *The central area* (which includes the historic center) is the destination for most of the daily movements (mandatory or voluntary). Due to the various activities carried on in this area which concentrates a high number of jobs, but also the direct access to the historic center, the car traffic is intense throughout the day, the waiting time in traffic is high (from 10 to 45 seconds) and the driving speed is low (average 30 km/h). Accessibility to public transport (bus and tram) is very high. In this area, be-sides walking, people can use the bike routes along Calea Bucureşti boulevard to access the central and core area.

- *Periphery / suburban area* characterized by the recent urban sprawl, where car transport (mostly individual) predominates and transport infrastructure occupies important areas (Avram S. et. al, 2010). Other land uses are attributed to new residential areas in continuous development, industrial and commercial spaces, as well as sports facilities.

The three areas identified are relatively concentric, being bounded by important traffic arteries that provide transit (to the east, towards Bucharest or to the west) or access to the central area, or bordered bypasses.

Starting from the relation between urban form and urban spatial structure, accessibility and agglomeration are the key elements that generate the main features of the urban transport in Craiova city. Thus, the first part of the study focuses on the accessibility of residential areas (especially the new residential areas within the suburban area) to collective transportation and identifies the problematic areas. The access of population, living in peripheral areas of the city, to transport system is very important as they depend on it for daily movements (work, school, shopping), using mostly personal cars. By identifying the coverage of the collective transport in these areas, the study highlights the need of improving the accessibility to bus or tram routes and the possibility of shifting the transport preferences from individual to collective. Although the population densities in these areas are low (fig. 2) compared to the ones in the rest of residential areas, they represent the main cause that generates intensive road traffic on collecting streets and increases the travel time and costs.

As the main growth pole of the region, the urbanised area of Craiova is continuously expanding, and the residential land use registered the most rapid growth during the last decade. Although the city is growing, the public transportation system did not registered major improvements, the only growing statistic being for the number of cars. There are 350 cars to 1,000 inhabitants in Craiova and 296 cars to 1,000 inhabitants in the metropolitan area.

Regarding the public transport, the city has a number of 140 buses out of which 17 are modern, purchased in 2014 and 17 have less than ten years of operation, the rest of 106 buses being older. Besides the buses, there are also 29 trams (older than 30 years) and 66 minibuses (33 belonging to a private company which provides services of public transport). The average life time in operation of buses is 15.47 years and 12.54 years for minibuses. The minibuses from the private company have an average operation of 4.15 years (*Urban Mobility Plan of Craiova*, 2017).

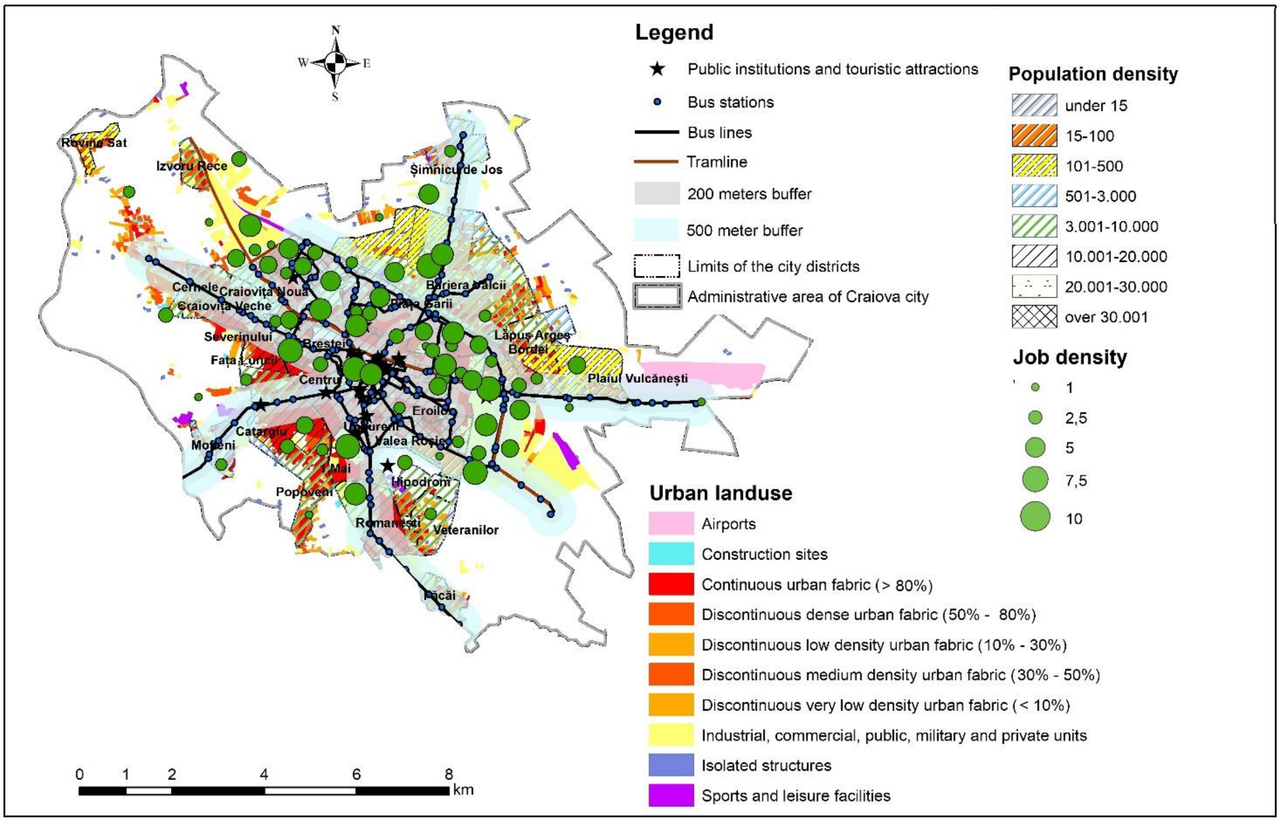

Fig. 2: Spatial distribution of public transport in relation to urban land use, population and job density

Source: population and job density data were processed using the information found in the Urban Mobility Plan of Craiova

From the first observations over the routes of public transport density and spatial distribution, the most reachable areas using this type of transportation, in a limited amount of time and a limited walking distance, are the old city center and the central area surrounding it (fig. 2). These areas can be accessed by bus lines (coming from different parts of the city) and by tram. Also, the density of stations is very high. As we are interested in the access of the population to the public transport, for our study we selected two situations in order to show the minimum distance and walking time to a bus station. For the first scenario, we used a 200 meters buffer around the bus line routes and their stations and in the second scenario a 500 meters buffer was applied. After spatial modelling different amount of geographic data, processing and overlaying the layers containing spatial information about the urban land use, urban density, functional areas, public transport routes and stops along these routes, the GIS data base was queried and several calculations had been made. The final data were converted in percentages for a better comparison. The results showed the following situations (Table 2):

Table 2: Urban land use within the selected buffers

Buffer	Total area		Residential			Other land use		
	(sq km)	% of total urban area	(sq km)	% of buffer area	% of total urban area	(sq km)	% of buffer area	% of total urban area
200 m	21.74	26.70	11.21	51.56	13.76	10.53	48.43	12.93
500 m	40.63	49.90	19.69	80	24.18	15.51	20	19.05

Source: calculations made by the author

The analysis shows that the total area covered by the 200 meter buffer from all the existing bus lines cover about a quater (26.7 sqkm) of the total urban area, while the area included within the 500 meter buffer almost 50% (Table 2). These results show that

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almost half of the activities existing within this area have access to the public transportation (fig. 2 & 3).

The „other" areas, except the residential ones, include the following types of urban land uses within the buffer area: commercial (including commercial, industrial and educa-tional), green areas, services and other. Also, from the total area covered by the 200 meters buffer, the central area has 3.87 sqkm, while the 500 meter buffer includes 5.43 sqkm from the central area. The green areas represent about 10% of the area covered by the 200 meter buffer and 14.34% of the area included within the 500 meters buffer.

In terms of accessibility, the following areas have been identified where public transport offers no service or low service levels (fig. 3):

• the eastern part of the city: the Carpen Street and the northern and eastern parts of Bordei district where the largest new continuous residential area has been devel-oped in the last decade;

• the wastern part: the area located westward of Râului Street and both sides along the Știrbei Vodă boulevard, both areas with new residential areas in development;

• the southern area: Veteranilor și Hipodrom districs, residential area mainly with individual households.

These neighborhoods require improved access to public transport by extending the existing routes or providing new ones. These areas can, however, raise problems of prof-itability either because they have a very low population density (due to the predominance of individual households), especially in the south and northeast, where there are also un-occupied lands or because they have a poor road infrastructure like in the southwest and western areas.

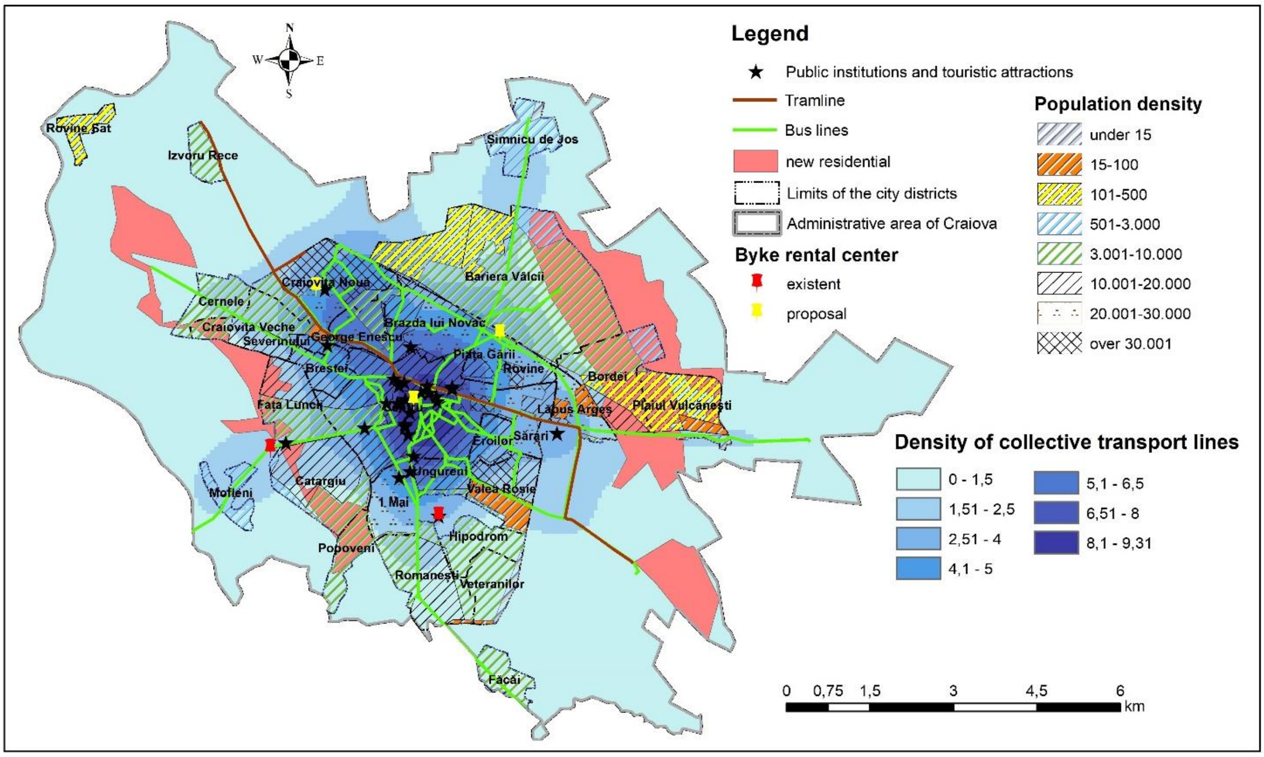

Fig. 3: Map of accessibility to public transport (bus lines and tramline) in relation to population density and main touristic objectives located in the central area

The raw data collected, as well as the field observations, showed two trends in road traffic congestion that contribute to traffic jams and increased waiting times. The analyzes showed that the main road arteries crossing the city from north to south (Amaradia street and Carol boulevard) and from east to west (Calea Bucureşti, AI Cuza, Caracal boule-vards) linking the access and entering points into the city, the residential areas and the city center are the most crowded roads. Also, the number of vehicles transiting these arteries varies between 1,000 up to 2,500 cars/ day. The spatial interpolation of data shows that the most probable cause of the road blockage is on the arteries connecting the northern part of the city (Şimnicul de Sus, Bariera Vâlcii) and its southern part (Mofleni where the ecologi-cal waste platform of the city is located), but passing through the central area. The second route is along the European road E70, which connects Bucharest and Timisoara and cross-es the city from east to west (fig. 4). Craiova is not only a production center, but also a big consumption center, therefore urban activities include also a large amount of freights es-pecially at the main access points in the city and on the city ring roads. Most of the indus-trial and large warehouses are located along the north ring road of the city. The heavy traf-fic is not allowed in the city, but there are some hot spots at the intersections connecting the main roads.

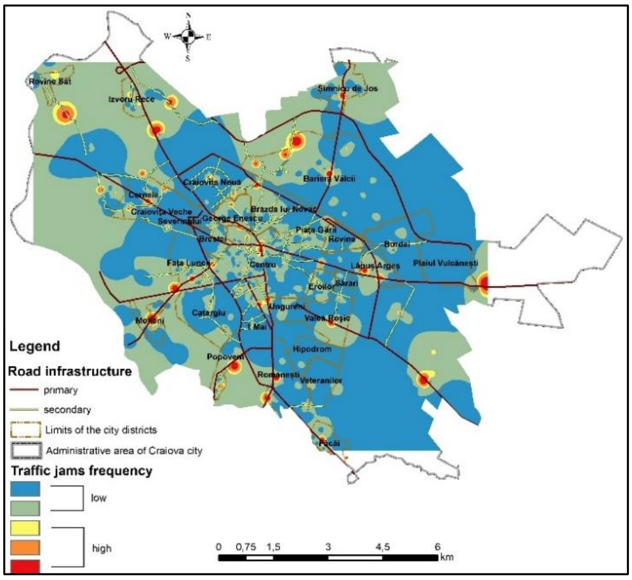

Fig. 4: Road sections with high probability of traffic delays due to traffic intensity on rush hours

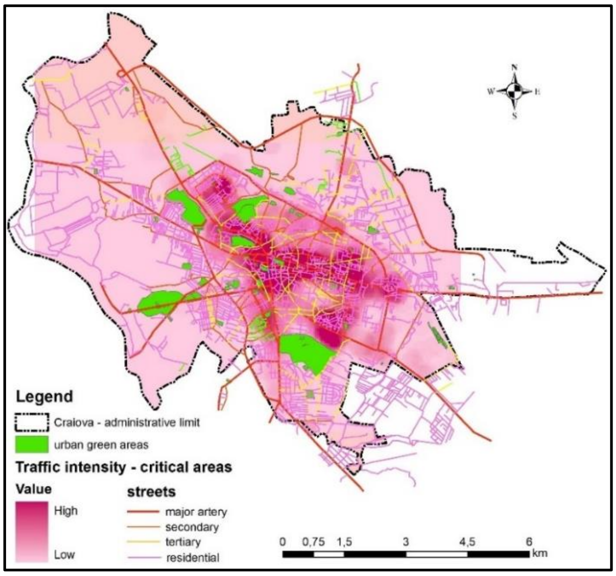

Fig. 5: Traffic intensity on main roads

The traffic intensity map (fig. 5) shows that there is a tendency of agglomeration toward the center, caused also by the numerous activities located within the perimeter enclosed by Dacia and Decebal boule-vards, Henry Ford and Caracal streets and Calea București and Tineretului boulevards. Also, this is the area with the highest density of jobs (fig. 2). The ac-tivities determined by the urban land use tend to take advantage of the value of a specific location. This value is connected to the accessibility to public transport of special infrastructure, closeness to the city center, production centers or market places. The value of the land determined by its use is also very important. The more valuable a location, the more likely agglomeration will take place. The organization of various activities is hierarchical, determined by the relationships between the agglomeration and acces-sibility at the local and regional levels (Rodrigue J.P., 2017).

Conclusion

The road network extension to new areas of urban growth is not considered a solu-tion by the authors; a better alternative would be the improvement of the access to public transport by setting up new routes or stations, modernizing buses and increasing their frequency. Although, recently upgraded, the tramline is one-way and only provides a link between the eastern and western parts of the city, with a reduced frequency on extended routes. Increased accessibility to public transport can also have the effect of decentralizing the activities located in the city center that can be relocated to the periphery with a higher level of accessibility. Through an increased accessibility, some locations may become more valuable for a range of activities, but at the same time, cheaper for development than in the central area. In addition to the development of suburban areas and the emergence of new services (educational, banking, commercial, health) that may determine residents from the new residential areas to reduce the number of movements, there is also a nega-tive effect materialized in the increase of land value.

Although the road traffic in the central area has been improved by modernization works like the construction of the supended and the underground passages, it remains among the busiest intersections, having the longest waiting times in traffic. Also, the main boulevard that crosses the city (Calea Bucuresti continued with Calea Severinului) and connecting the arteries (Amaradia, A. I. Cuza, Carol Carol) are very crowded mostly due to the use of personal cars.

As in most large cities, the lack of parking places is another aspect that creates traf-fic problems in Craiova. The time spent to find a parking space in the central area, alt-hough there is an underground parking place for small cars, determines drivers to spend more time in traffic or to park irregularly thus blocking the traffic or the access of buses to stations.

Sustainable transportation should be though measures and metropolitan develop-ment plans issued by local authorities. The management of transpotation should aim the control of local development in the urban fringe of Craiova city. It is also recommended to increase the length of bicycle tracks, including in the historical part of the city, as well as rent centers. This measure was already foreseen in the Urban Mobility Plan of Craiova. The improvement of urban road traffic can also be achieved by using components of traffic management systems, in particular through optimization softwares or by increasing the number of video surveillance intersections or by increasing the number of traffic boards with informative messages, both for public transport and car traffic.

If we understand the relationship between urban form, land use and transport, one can find the best solutions to regulate the transport and movement of people and freights.

Another solution for solving part of the traffic problems may be the regulation of urban access by using road user charging schemes for certain areas like city center. Also taxation can be applied depending on the technical specification of cars, but defining these features may be rather difficult. Although few European cities use urban road user charging, some take into considetarion to regulate the traffic of diesel cars in the future. Craiova may consider one of these options, as the first step in limiting traffic in central areas was taken by mounting access barriers for residential areas within the old town.

Traffic fluidity is measured by the amount of transportation costs. Additionally, the more time ones spends in traffic the more one increases the air pollution which directly affects human health. Thus, concepts like car sharing, electric public transportation, hy-brid vehicles or new alternatives for peoples' movement may be a viable solution to reduce traffic, transporation costs and additional pollution.

References

Avram Sorin, Curcan Gheorghe, Vladut Alina, Marinescu Ioan, (2010), Improvement of urban road traffic in Craiova city by using GIS data processing, 3rd INTERNATIONAL CONFERENCE ON CARTOGRAPHY AND GIS, Nessebar, Bulgaria

Banister D., (2008), The sustainable mobility paradigm, Elsevier, Trasnport Policy, 15, pp. 73-80

Belik, V., Geisel, T. & Brockmann, D., (2011), Natural human mobility patterns and spatial spread of infectious diseases. Phys. Rev. X 1, 011001.

Berry, J., 1987, Fundamental operations in computer-assisted map analysis, International Geographical Information System, 8, pp. 45-70.

Coulter, L., D. Stow, B. Kiracofe, C. Langevin, D. Chen, S. Daeschner, D. Service, and J. Kaiser, 1999, Deriving Current Land-Use Information For Metropolitan Transportation through Integration of Remotely Sensed Data and GIS, Photogrammetric Engineering & Remote Sensing, Vol. 11, pp. 1293-1300.

Ford, A. C., Barr, S. L., Dawson, R. J. and James Ph., (2015), Transport Accessibility Analysis Using GIS: Assessing Sustainable Transport in London, ISPRS Int. J. Geo-Information, 4, 124-149; doi:10.3390/ijgi4010124.

Gonzalez, M. C., Hidalgo, C. A. & Barabasi, A.-L. Understanding individual human mobility patterns. Nature 453, 779–782 (2008).

Gutiérrez J, García-Palomares J.-C., 2008, Distance-Measure Impacts on the Calculation of Transport Service Areas Using GIS, Environment and Planning B: Urban Analytics and City Science Vol 35, Issue 3, pp. 480 – 503, doi: 10.1068/b33043

Issa M. El-Shair, (2009), GIS and Remote Sensing in urban transportation planning: A case study of Birkenhead, Auckland

Mir Shabbar A., Muhammad A., Syed Muhammad N., Syed Fazal Abbas B., (2014), Estimation of Traffic Congestion Cost-A Case Study of a Major Arterial in Karachi, Procedia Engineering 77, pp 37 – 44

Pengjun Zhao, (2010), Sustainable urban expansion and transportation in a growing megacity: Consequences of urban sprawl for mobility on the urban fringe of Beijing, Elsevier, Habitat International, 34, pp. 236-246

Rodrigue J.-P., (2017), The Geography of Transport Systems, fourth edition, Routledge, New York, ISBN 978-1138669574

Wang L., Chen H., and Li Y., (2014), Transition Characteristic Analysis of Traffic Evolution Process for Urban Traffic Network, The Scientific World Journal, http://dx.doi.org/10.1155/2014/603274

Yi Jiang, (2001), Estimation of Traffic Delays and Vehicle Queues at Freeway Work Zones, Transportation Research Board 80th Annual Meeting, Washington, D.C

CE, (2013), Together towards competitive and resource-efficient urban mobility, Annex 1, A CONCEPT FOR SUSTAINABLE URBAN MOBILITY PLANS

CE, (2013), A call for smarter urban vehicle access regulations and Mobilising Intelligent Transport Systems for EU cities

**** Plan de mobilitate urbană durabilă pentru polul de creștere Craiova (P.M.U.D. Craiova), Raport Final (2015)

U.S. Department of Transportation, Federal Highway Administration, (2007), Traffic Analysis Toolbox Volume VI: Definition, Interpretation, and Calculation of Traffic Analysis Tools Measures of Effectiveness, Washington (https://ops.fhwa.dot.gov/publications/fhwahop08054/fhwahop08054.pdf)

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Mapping spatial urban growth and land use change using geoinformatics technique in Varanasi District, Uttar Pradesh, India

Sunita SINGH[1*]

[1] Department of Geography, Banaras Hindu University, Varanasi, India
* *Corresponding author*: sunbhu11@gmail.com

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Abstract

Urban growth is a worldwide phenomenon, but the rate of urbanization is very fast in developing countries like India. It is mainly driven by unorganized expansion, increased immigration, rapidly increasing population. In this context, land use and land cover change are considered central components in current strategies for managing natural resources and monitoring environmental changes. Uncontrolled momentum of urban sprawl and land use change raises many issues which might have both positive and negative effects. This sprawl can be effectively monitored using remotely sensed data from different dates by digital analysis of the imagery using change detection techniques.
The present study aims to examine the change in urban sprawl, land use/land cover (LU/LC) over a time point and assesses the pattern of sprawl through GIS technique. The geographical area of Varanasi district is 1535 sq.km including 1,371.22 km² rural area and 163.78 km² urban area, its population is 3,676,841 persons in 2011. It consists of eight blocks namely Baragaon, Pindra, Cholapur, Chiraigaon, Harahua, Sevapuri, Arajiline and Kashi Vidyapeeth. The spatio-temporal study of LU/LC as well as settlement is carried out for two time points 1990 and 2016. The data source used for analysis is Landsat MSS and Landsat OLI. The analysis mainly focused the urban growth along with landuse/landcover changes using digital image processing techniques like Maximum Likelihood Classifier algorithm for Supervised Classification and NDVI vegetation index. The trend of sprawl is notably higher in the urban centers than in the revenue villages.

Keywords: *urban growth, land use, NDVI, remote sensing.*

Rezumat. Cartarea expansiunii spaţiale urbane şi a schimbărilor în utilizarea terenurilor folosind tehnica geoinformatică în Districtul Varanasi, Uttar Pradesh, India

Expansiunea urbană este un fenomen mondial, iar rata de urbanizare este foarte rapidă în ţările în curs de dezvoltare, cum este cazul Indiei. Aceasta se datorează în principal expansiunii neorganizate, imigrației sporite, populației în creștere rapidă. În acest context, utilizarea terenurilor și acoperirea terenului sunt considerate componentele centrale ale strategiilor actuale de gestionare a resurselor naturale și de monitorizare a schimbărilor de mediu. Avântul necontrolat al dezvoltării urbane și al schimbărilor în utilizarea terenurilor ridică numeroase probleme care ar putea avea efecte pozitive, dar și negative. Această extindere urbană necontrolată poate fi monitorizată eficient utilizând date aparţinând teledetecţiei, de la momente diferite, prin analiza digitală a imaginilor, utilizând tehnici avansate de detectare a modificărilor.
Prezentul studiu își propune să examineze modificările referitoare la expansiune urbană, la utilizarea terenurilor/acoperirea terenului (LU/LC) pe o perioadă de timp și să evalueze modelul de extindere prin tehnici SIG. Aria geografică a districtului Varanasi este de 1535 kmp, incluzând o arie rurală de 1371,22 kmp și o arie urbană de 163,78 kmp, iar populația era de 3676841 persoane în 2011. Se compune din opt unităţi administrative: Baragaon, Pindra, Cholapur, Chiraigaon, Harahua, Arajiline și Kashi Vidyapeeth. Studiul dinamicii spațio-temporale a utilizării/acoperirii terenurilor s-a efectuat pentru două repere temporale: 1990 și 2016. Sursele de date utilizate pentru analiză sunt Landsat MSS și Landsat OLI. Analiza s-a concentrat în principal asupra creșterii urbane, împreună cu schimbările în utilizarea/acoperirea terenurilor utilizând tehnici de procesare a imaginilor digitale, cum ar fi algoritmul de clasificare a riscurilor maxime pentru clasificarea supravegheată și indicele de vegetație NDVI. Tendința de extindere necontrolată este semnificativ mai mare în centrele urbane decât în unităţile administrative rurale.

Cuvinte-cheie: *expansiune urbană, utilizarea terenurilor, NDVI, teledetecţie*

Introduction

Land-use is inclined by economic, cultural, political, historical and land-tenure factors at multiple scales. Land-use referred to as man's activities and various uses which are undertaken upon land. Urbanization is inevitable, when pressure on land is high, agriculture incomes are low and increasing demographic pressures become excessive as is the case in most developing countries of the world.

In India, a vast majority of the population lives in urban areas or regularly commutes in and out of urban areas. Urban sprawl poise to handicap effective allocation of limited resources and infrastructure facilitation becomes challenging to the authorities. Sprawl seems to threaten every chance of sustainable development of a country as it encroaches in to other important land-uses such as agriculture, wetland, forest, open spaces and recreational parks. In order to prevent this type of growth, monitoring urban development through measures such as legislation, zonation, preparing master plan etc. has become imperative. Across developing countries there is not growing awareness and concern about urban growth, which has different background in the cities of China, Europe and North America. Land development has been out of control and the construction land has kept expanding blindly, especially in the marginal areas of some metropolises. Nowadays urban areas experience fast growth due to enormous population growth, rapid industrialization, economic development and specific economic policies adopted by governments and immigration of people from villages to cities. Accelerated urban growth is usually associated with and driven by the population concentration in an area. The extent of urbanization or its growth drives the change in land use/cover pattern. The rapid changes of land use and cover are often characterized by uncontrolled urban sprawling, land degradation or the transformation of agricultural land to farming resulting enormous cost to the environment (Sankhala&Singh, 2014). Uncontrolled urbanization has been responsible for many of the problems our cities experience today, resulting in substandard living environment, acute problems of drinking water, noise and airpollution, disposal of waste, traffic congestion etc.

Remote sensing imageries and techniques showed considerable potentials for urban growth and land-use analysis. Land-use and land-cover classes (LU/LC) are important indicators for understanding the connections between surroundings and human activities which can be efficiently obtained from satellite imageries through image classification. The availability of remotely sensed data from multiple dates enables to carry out studies on multitemporal urban modeling. The extent of urban areas can be automatically identified from satellite imagery using machine learning algorithms. Change detection analysis can be carried out to measure the changes between two LU/LC maps from different periods of time.

Recently, remote sensing has been used in combination with GIS and Global Positioning Systems (GPS) to assess land-cover change more effectively than by remote sensing data only (Dewan et al., 2012; Boori et al., 2015a). It has already proved useful in mapping urban areas and as data source for the analysis and modeling of urban growth and land use/land cover change (e.g., Rodriguez-Galiano&Chica-Olmo, 2012; Grey et al., 2003; Herold et al., 2003; Wilson et al., 2003).

Remote sensing data is very useful because of its synoptic view, repetitive coverage and real time data acquisition. The satellite data in digital form therefore, enable to accurately compute various land cover/land use categories and help in maintaining the spatial data infrastructure which is essential for monitoring urban expansion and land-use studies (Mukherjee, 1987). The purpose of using GIS is that maps provide an added dimension to data analysis, which brings us one step closer to visualizing the complex patterns and relationships that characterize real-world planning and policy problems. Visualization of spatial patterns also supports change analysis, which is important in monitoring social indicators. This in turn should result in improving need assessment. The objectives of this paper is to explain remote sensing and GIS applications in various stages of planning, implementation and monitoring of the urban area.

Overview of Change Detection Techniques in Urban Areas

A variety of change detection techniques are available for monitoring land use/land cover changes. These techniques can be grouped into two main categories: post-classification comparison techniques and enhancement change detection techniques (Nelson, 1998).

The post-classification technique involves the independent production and subsequent comparison of spectral classifications for the same area at two different time periods (Mas, 1999). Post classification techniques have the advantage of providing direct information on the nature of land-cover changes. The classification process used with these techniques can be either supervised or unsupervised. Sohl (1999) reported accuracies of 96 per cent for the identification of new forest land and 62 per cent for new agricultural land using a post-classification technique in a semi-arid environment. Furthermore, Sohl (1999) noted the accuracy of the method for providing users with a complete descriptive comparison between images. Pilon et al. (1988) employed post-classification in combination with a simple enhancement technique to differentiate areas of human induced change from areas of natural change. Mas (1999) also obtained the highest accuracy with this technique in a study comparing six different techniques.

Enhancement Change Detection Techniques involve the mathematical combination of images from different dates which, when displayed as a composite image, show changes in distinctive colors (Pilon et al., 1988). The enhancement change detection techniques have the advantage of generally being more accurate in identifying areas of spectral change (Singh, 1989).

Image Differencing Technique

Image differencing is a technique by which registered images acquired at different times have

DN values for one band subtracted from the corresponding DN values from the same band in the second image to produce a residue image, which represents the change between the two dates (mass1990). Ridd&Liu (1998) reported image differencing was fairly effective in its ability to detect change in an urban environment, with TM band 3 producing the highest accuracies. Sunar (1998) and Sohl (1999) reported that the image differencing technique was extremely straightforward, but with the qualification that image differencing technique becomes slightly more complicated when using multiple bands, instead of single bands, due to the difficulty of interpreting the colors of multiband false color composites.

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) estimates the vitality of vegetation by exploiting the known gap in vegetation reflectance between the visible and near infrared channels. Common change detection methods include the comparison of land-cover classifications, multi-date classification, band arithmetic, simple rationing, vegetation index differencing and change vector analysis (Jomaa, 2003). The NDVI is calculated as a normalized ratio (ranging from -1 to1 from the NIR and the red band and emphases apparent vegetation (Sabins, 1996).

Study area

Varanasi district comes between 25°10′ to 25°37′ N latitude and 82°39′ to 83°10′ E, lies in eastern Uttar Pradesh, India (Fig. 1). Physiographically, it lies in the Middle Ganga Plain. The district is bounded by river Gomati and Jaunpur district in the north, Mirzapur in south, Sant Ravidas Nagar Bhadohi in the west and Chandauli district in the east. This district is divided in to eight blocks, namely: Araziline, Baragaon, Chiraigaon, Cholapur, Haruha, Kashi Vidya Peeth, Pindra and Sewapuri. Morphologically, the study area is covered by the alluvial deposits of Quaternary age. Ganga is the main river of the District. Geologically the district is made of Gangetic alluvium formed by the deposition of the sediments brought by the Ganga river and its tributaries. The tributaries are Gomti, Varuna, Asi, Banganga, Chandra Prabha and Karmanasa, that drain the area. It consists mainly of sand, silt and clay mixed by kankar at a few places. The area comes under subtropical monsoonal climate characterized by seasonal extremities. January is the coldest month with mean maximum temperature of 23°C. Sometimes, the minimum temperature may go around 5°C during December and January, coupled with occurrence of dense fog. June is the hottest month with mean maximum temperature around 35°C. However temperatures' soaring above 40°C is not uncommon, with occasional rise above 45°C under the impact of heat wave and hot air blowing in May and June, locally named *loo*. The average annual rainfall of the district is around 110 cms bulk of which is received from the south west monsoons during June to September, August the rainiest month.

Data used and methodology

Survey of India toposheet (1:50,000) and satellite data Landsat (TM) of 1990 and Landsat 8 (OLI&TIRS having 30 m resolution) of 2016 has been used. The Survey of India toposheet and satellite images have been geometrically corrected and rectified using ERDAS Imagine 14.

The study area map was prepared from SOI topographical sheets on 1:50,000 scale. The settlement in the study area, during 1990 and 2016 were derived from the Satellite images and werecompared with one another to carry out change detection studies for the period 1990 and 2016.The same classes were then visually interpreted from the 1990 satellite data by using the common image interpretation elements. Necessary field checks were carried out and corrections were made at required places. Then, the software such as Arc GIS 10.3 and Erdas imagine14 were used to prepare the urban settlement cover changes during 1990-2016.

Change Detection Methods adopted

The change detection techniques will be discussed, using the two main categories, post classification comparison techniques and enhancement change detection techniques described in the literature section.

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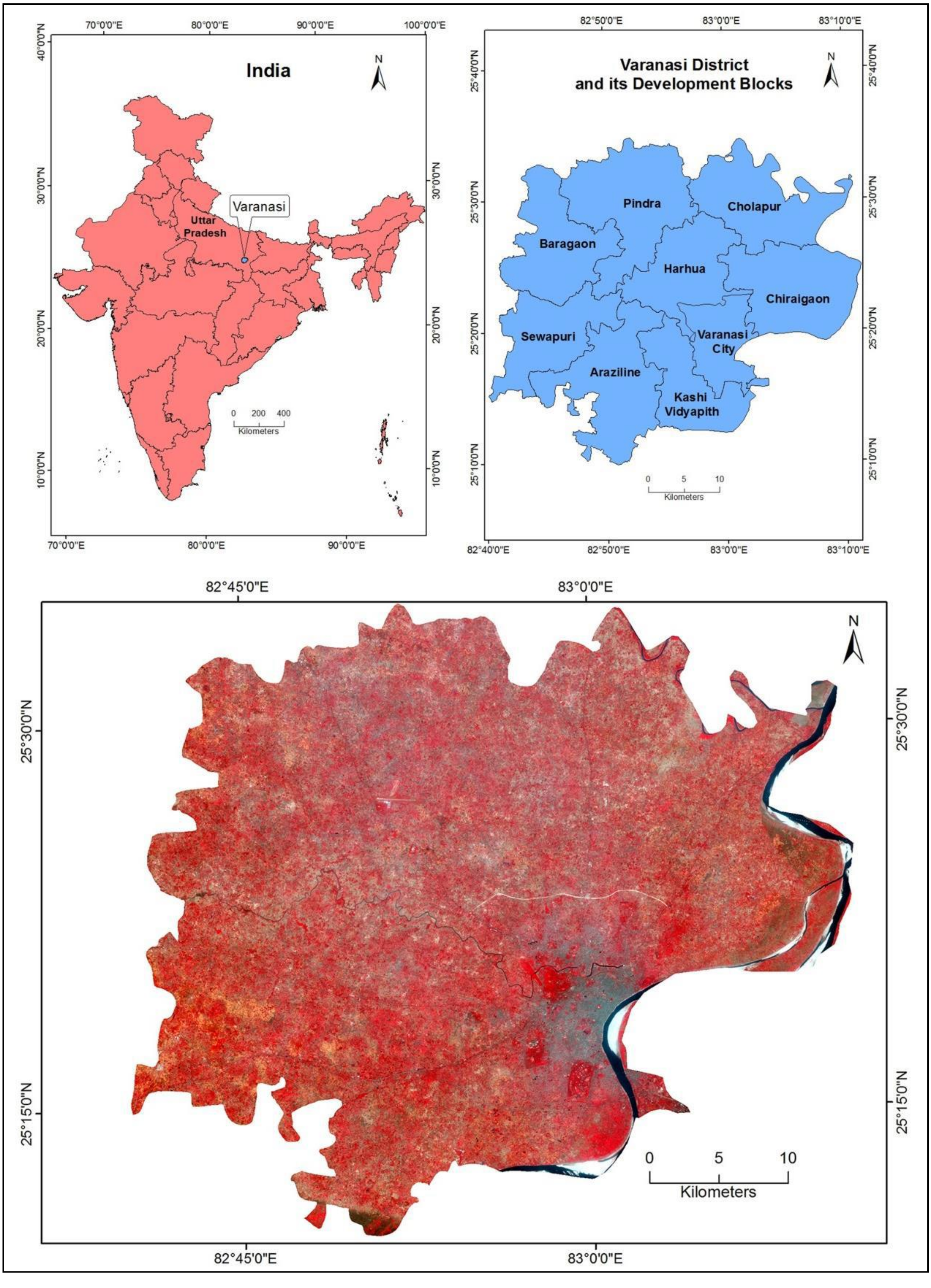

Figure 1: Location of the study area

Table 1: Details of Landsat images used in the study

Satellite sensor	Path/Row	Date of aquisition	Cloud coverage
Landsat-5 TM	142/42 142/43	February,18th, 1990	no
Landsat 8-OLI TIRS	142/42 142/43	February, 3rd, 2016	no

Geometric and Radiometric Correction

The images were co-registered to each other using ground control points (GCPs). Hundred GCPs were collected and the number of GCPs was reduced to ten in order to achieve an acceptable RMS error. The RMS error was 0.44. The X RMS error was 0.36 and the Y RMS error was 0.25. The images were resampled with cubic convolution (3). Both of the images' pixel spacing was set to 30 m. The images were then atmospherically corrected using calibration files in the software (ENVI-5.3).

Radiometric correction was performed on the images using pseudo-invariant features (PIFs). Google map was used as reference to verify the nature of the features.

Image analysis

Image Classification Techniques

In this study, Anderson classification system (Level 1) was adopted for the selection of LU/LC classes. This approach is most appropriate to prepare land use/cover maps from remote sensing data, specifically Landsat data (Alrababah&Alhamad 2006, Rozenstein&Karnieli 2011, Zhu&Woodcock 2014). A total of 100 training areas were selected on the image, checked with field survey and seven LU/LC classes were made. These signatures were used for supervised classification incorporating maximum likelihood classification (MLC) algorithm that was run with a feature-space non-parametric decision rule. Afterwards, all classes are merged into suitable seven classes using recode function.

Post-Classification processing

Supervised classification provides unsatisfactory classification results because of Spectral confusion. Spectral similarity of various objects causes such confusion. For example, barren land and agricultural fallow land; settlement and open forest each are often erroneously classified into other class. To avoid such problems, post-classification processing of the classified maps was employed in the study. The post classification processing included in this study is recoding of classified erroneous classes to appropriate classes based on digitized polygons of LU/LC classes obtained from Google earth image and satellite images. For this operation, hundreds of polygon that cover the patch of built-up area, agricultural land, barren land, river channels, open and dense forests were digitized on Google earth image. Most of the built-up area, barren lands and river channels were digitized; while some selected part of agricultural land and forested area were digitized. For the fine tuning, small patches of built-up, barren and agricultural land in the most confusing part were also digitized. The digitized polygons were converted into AOI and within AOI LU/LC image were changed by recoding. Finally, to remove 'salt&paper' noise that quite appears in digital image processing, a majority filter (3X3 filter) was employed for three classified images.

Results and discussion

Change detection

The analysis reveals the following information and changes also shown in clearly in Table no. 2. This will help the planners and other researchers for further research at both micro level and macro level. The changes are mostly cause of human inference which affects the natural ecosystem one or other way. The normal temperature raised significantly compares with last 3 decades this result of urbanization and settlement expansion.

It is apparent that urban expansion is maximum than all the other land classifications. In short, the results have shown that there is a significant increase in urban expansion leading to a significant drop in fallow land, marshy land and barren land during the study period. It is thought that the main explanation for the rapid increase in urban area is population growth, migration from rural areas to Varanasi city and more general economic development. The marsh area has decreased from 0.69 per cent in year 1990 to 0.07 per cent in the year 2016. It is noticed that a heavy flood in Varanasi in 1978 which increased marsh land during early time periods. During the study, it is shown that the area under the vegetation or orchards has increased from 1990 (6.13 per cent) to 2016 (9.65 per cent). It shows gradual increase from 1990 to 2016, due to people's increased awareness and to the governmental plan.

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Table 2: Area Distribution of Land Use Land Cover (%) and change in area (%)

LU/LC Classes	Area (%) 1990	Area (%) 2016	Change in area (%) 1990-2016
Water body	2.75	1.99	-0.76
Fallow Land	40.12	10.07	-30.05
Crop Land	41.91	53.07	+11.16
Sand Bar	0.95	1.28	+0.33
Barren Land	0.96	0.03	-0.93
Built Up Area	**6.94**	**23.82**	**+16.88**
Vegetation	6.13	9.65	+3.52
Marsh Land	0.69	0.07	-0.62
Total Area	100	100	--

Note: Positive (+) values indicate gain in the area whereas negative (-) values indicate loss in area

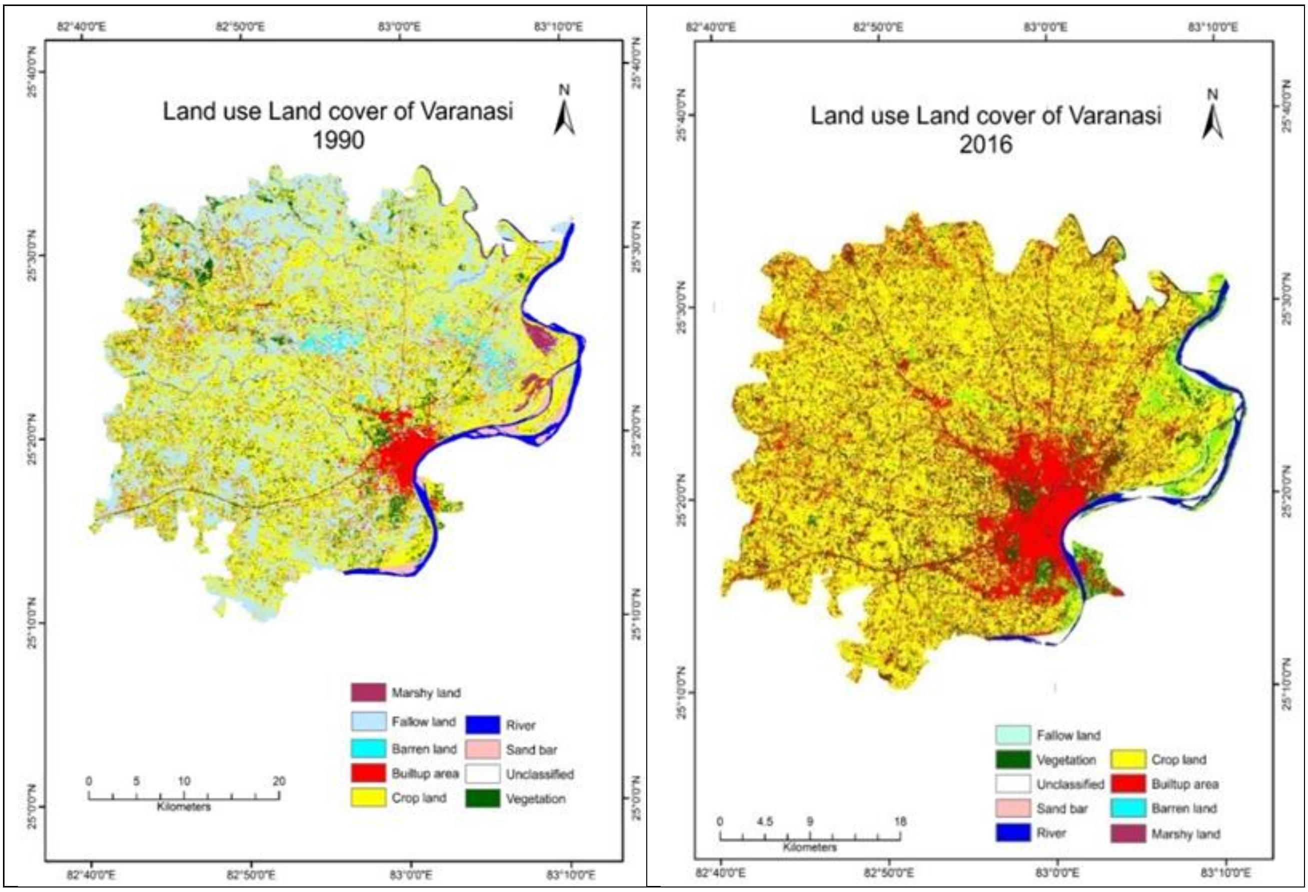

Figure 2: LULC Map of 1990 &2016

Normalized difference vegetation index (NDVI)

NDVI is calculated from the visible and near-infrared light reflected by vegetation. NDVI has proved to have an extremely wide (and growing) range of applications. It is used to monitor vegetation conditions and therefore provide early warning on droughts and famines. Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1); 0 means no vegetation, (0.8-0.9) indicates the highest possible density of green leaves. 0 to -1 indicated higher red reflectance than NIR. Water typically has an NDVI value lower than 0, bare soils between 0 and 0.1 and vegetation over 0.1.

The NDVI analysis reveals that: (1) decrease in NDVI between two scenes will be the result of new development and (2) increase in NDVI between two scenes will be the result of forest re-growth; (3) urban changes in red signal may be unrelated to vegetation (Source: NSAS Earth Observatory).

The NDVI of multi-temporal data result (Fig. 3) shows that there is increase in built-up area. The urban extent of Varanasi city has increased tremendously: the built-up area has changed from 6.94% in 1990 to 23.82% in 2016.

Accuracy assessment

The ground truth data collected with GPS were used as the reference for assessing the accuracy of classification. The accuracy and KAPPA statistic of the classified image checked with the help of accuracy assessment. The overall accuracy of the image is given in the Table no. 3.

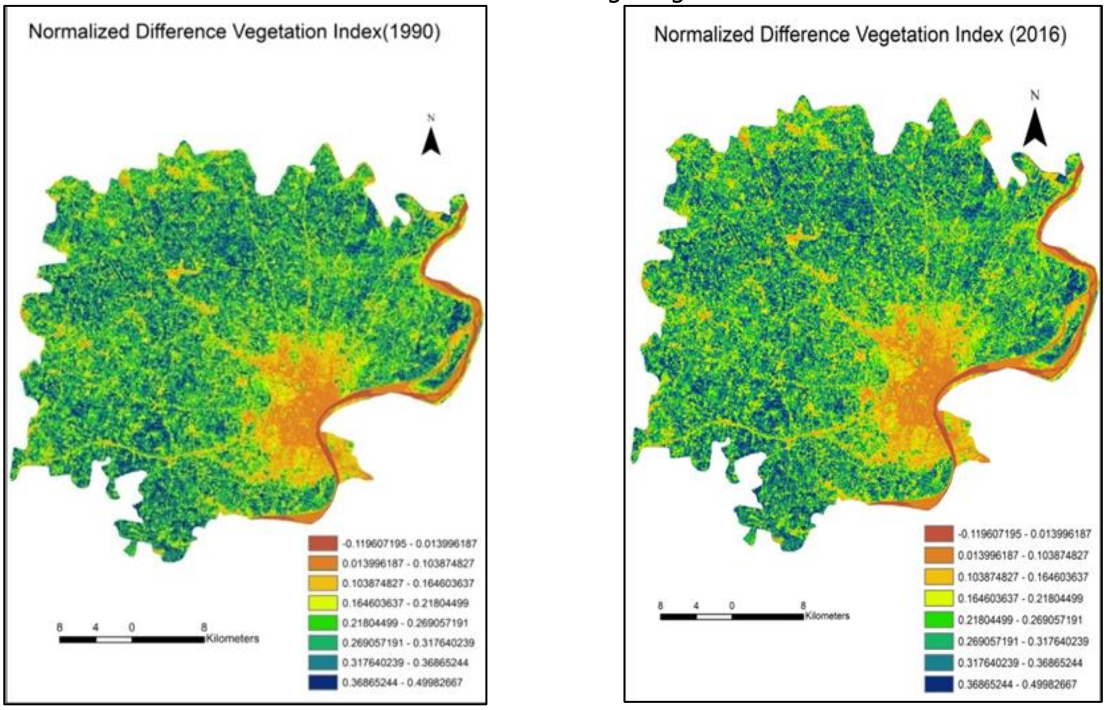

Figure 3: NDVI Map of 1990 &2016

Table 3: Overall accuracy of classified images

Year	Overall accuracy
1990	84%
2016	90%

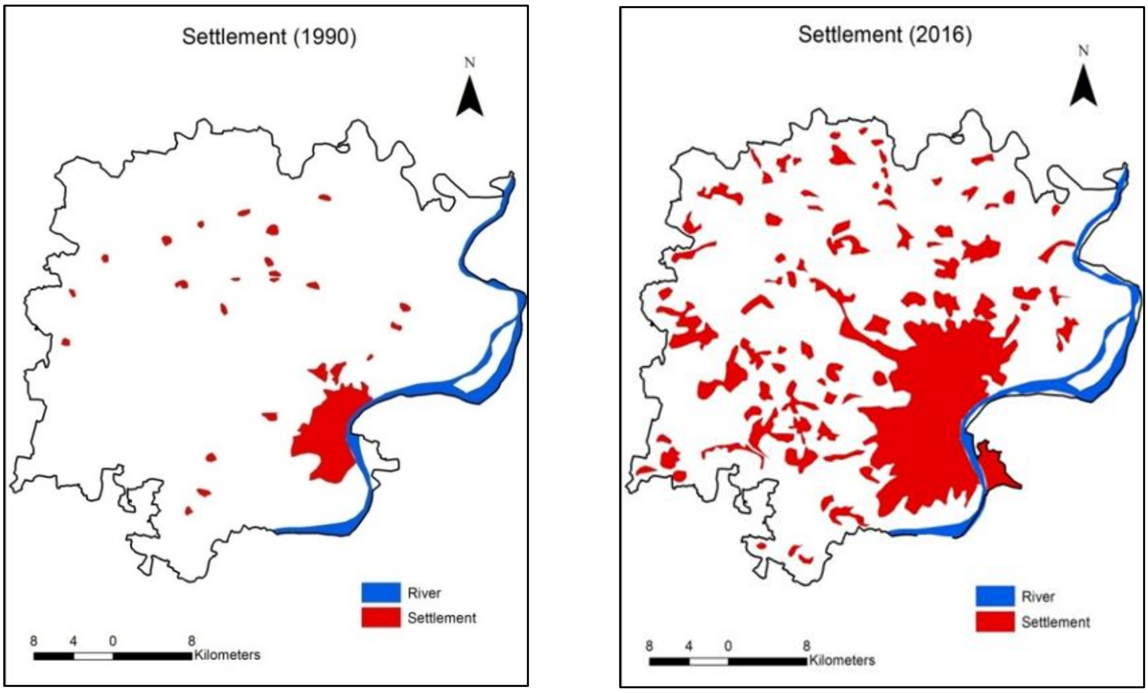

Figure 4: Settlement Map of 1990 &2016

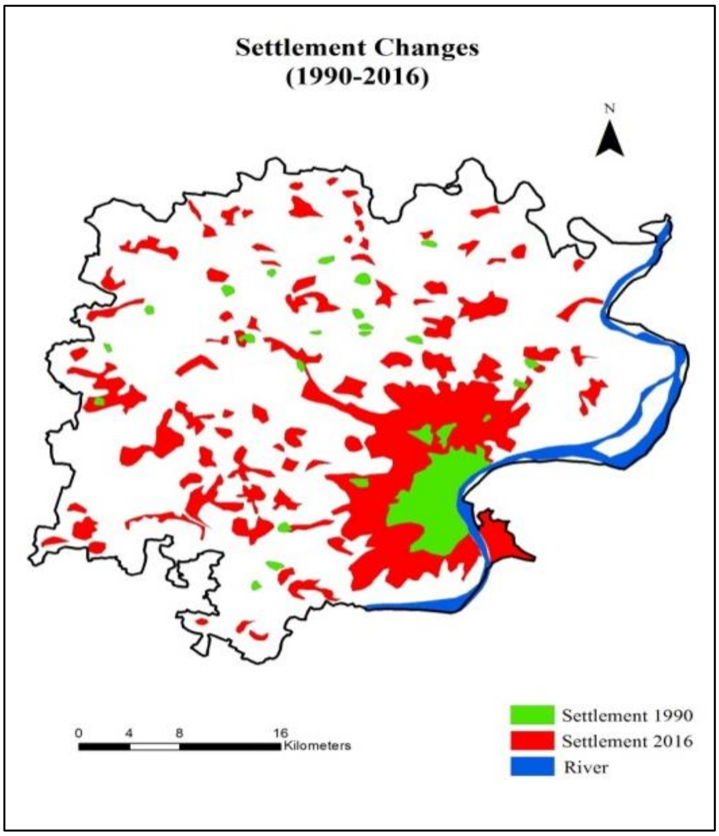

Figure 5: Settlement changes from 1990 to 2016

Conclusion

Urban dynamics research provides vital clues for evolving appropriate land use policy for sustainable management of natural resources. The results clearly reveal the significance of the use of multi-temporal Landsat data which offers an accurate and economical way of mapping and conducting analysis on the changes in LU/LC during the study period 1990-2016. Geographical information system (GIS) have been used in this study to provide spatial inputs and preparing maps for comparing changes.

The study has identified several patterns and trends of the changes in LU/LC in the area. It is apparent that the built-up areas resulting from urban expansion hold primary position as compared to all the other land classifications. In short, the results have shown that there is a significant increase in urban expansion leading to a significant drop in agricultural land-use and vegetation during the study period. Urban sprawl is taking place continuously at a faster rate in outskirts and buffer regions. It is thought that the main explanation for the rapid increase in urban area is population growth, migration from rural areas to the Varanasi city and more general economic development. Identification and analysis of the sprawl patterns would help in effective land use planning and environmental management in urban area.

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References

Alrababah, M. A., Alhamad, M. N. (2006). Land use/cover classification of arid and semi-arid Mediterranean landscapes using Landsat ETM. International Journal of Remote Sensing, 27, 2703.

Boori, M.S., Vozenilek V., Choudhary, K. (2015a) Exposer intensity, vulnerability index and landscape change assessment in Olomuc, Czech Republic, Int Arch Photogramm Remote SensSpatial Inf Sci XL-7/W3:771–776. doi:10.5194/isprsarchives-XL-7-W3-771-2015

Dewan, A.M., Yamaguchi, Y., Rahman, M.Z. (2012) Dynamics of land use/cover changes and the analysis of landscape fragmentation in Dhaka Metropolitan, Bangladesh, Geo J 77(3):315–330.

Fung, T., Le Drew E. (1987). Application of Principle Component Analysis to Change Detection.

Photogrammetric Engineering Remote Sensing: 53: 1649-1658.
Herold, M., Goldstein, N., Clarke, K.C. (2003). The spatio-temporal form of urban growth: measurement, analysis and modeling. Remote Sensing of Environment, 86(3), 286–302.
Jomaa, I. , Kheir Bou, R. (2003). "Multitemporal unsupervised classification and NDVI to monitor Land cover change in Lebanon (1987-1997)" National Council for Scientific Research/National Center for Remote Sensing, Beirut, Lebanon.
Kumar Jat, M., Garg, P.K., Khare, D. (2008). Monitoring and modeling of urban sprawl using remote sensing and GIS techniques, International Journal of Applied Earth Observation and Geoinformation, 10, 26-43.
Li, X., Yeh, A. (1998). Principle Component Analysis of Stacked Multi-Temporal Images for the Monitoring of Rapid Urban Expansion in the Pearl River Delta, International Journal of Remote Sensing, 19 (8), 1501-1518.
Mas, J. F. (1999). Monitoring land-cover change: a comparison of change detection techniques., International Journal of Remote Sensing, 20, 139–152.
Mishra, V.N., Rai, P.K., Kumar, P. Prashad, R., (2016). Evaluation of Land Use/Land Covers Classification Accuracy Using Multi-Temporal Remote Sensing Images, Forum Geografic. Studii de geografie şi protecţia mediului (Romania), 15 (1), 45-53.
Mukherjee, S. (1987). Land use maps for conservation of ecosystems, Geog. Rev. India, 3, 23–28.
Nielson , A., Conradsen, K., , Simpson, J. (1998), Multivariate alteration detection (MAD) and MAF post processing in multi-spectral bi-temporal image data: new approaches to change detection studies, Remote Sensing of Environment, 64, 1–19.
Rai, P.K., Singh, S., Mohan, K. (2015). Land Use Change Detection Using Multi-Temporal Satellite Data: A Case Study of Haridwar District, Uttrakhand, Journal of Scientific Research,Institute of Science, Banaras Hindu University, 59 (1&2), 1-16.
Rozenstein, O., Karnieli, A. (2011). Comparison of methods for land-use classification incorporating remote sensing and GIS inputs, Applied Geography, 31, 533–544.
Rodriguez-Galiano V., Chica-Olmo, M. (2012). Land cover change analysis of a Mediterranean area in Spain using different sources of data: multi-seasonal Landsat images, land surface temperature, digital terrain models and texture. Applied Geography, 35(1), 208–218.
Sankhala, S., Singh, B. (2014). Evaluation of urban sprawl and land use land cover change using remote sensing and GIS techniques: a case study of Jaipur City, India, International Journal of Emerging Technology and Advanced Engineering. 4 (1), 66–72.
Singh, A. (1989). Digital Change Detection Techniques Using Remotely Sensed Data, International Journal of Remote Sensing, 10, (6), 989-1003.
Sohl, T.L. (1999). Change Analysis in the United Arab Emirates: An Investigation of Techniques. Photogrammetric Engineering and Remote Sensing, 65(4), 475 – 484.
Sunar, F. (1998). An Analysis of Change in a Multi-date Data Set: A Case study in The Ikitelli Area, Istanbul, Turkey, International Journal of Remote Sensing, 19, 225-235.

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An evaluation of the human resources potential of the Western Region (Romania)

Sorin PAVEL[1,*], Sebastian JUCU[1]

[1] West University of Timisoara, Department of Geography, Blvd. V. Pârvan 4, 300223 Timisoara, Romania
* *Corresponding author*: sorin.pavel@e-uvt.ro

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Abstract

The data analysed in the present study show that the human resources potential of the Western Region is limited in nature and characterised by disparities that are multidimensional from both the quantitative and the qualitative point of view. When we consider the region in terms of its administrative sub-units, we find areas that have human resources that are surplus to requirements but insufficiently developed and structurally unbalanced (Hunedoara county), others with high-quality but numerically limited human resources and with great potential for attracting them from other areas (Arad and Timiş counties) and a case of an area whose human resources are both insufficiently developed and deficient from a quantitative point of view (Caraş-Severin county).

Keywords: *human resources, workforce/labour force, unemployment, Western Region, Romania*

Rezumat. O evaluare a potențialului resurselor umane din Regiunea de Vest a României

Datele analizate în acest studiu arată că potențialul resurselor umane din Regiunea Vest este limitat din punct de vedere natural și caracterizat prin disparități care sunt multidimensionale din punct de vedere cantitativ și calitativ. Când luăm în considerare regiunea din punct de vedere al subunităților administrative, există zone care au resurse umane excedentare cerințelor, dar insuficient dezvoltate și dezechilibrate din punct de vedere structural (județul Hunedoara), altele cu resurse umane de înaltă calitate, dar cu resurse limitate numeric și cu mare potențial de atragere a acestora din alte zone (județele Arad și Timiș) și cazul unei zone ale cărei resurse umane sunt insuficient dezvoltate și deficitare din punct de vedere cantitativ (județul Caraș-Severin).

Cuvinte-cheie: *resurse umane, forță de muncă, șomaj, Regiunea de Vest, Romania*

Introduction

The Western Region in its present-day boundaries includes a historic territory (Banat) in which human resources have always constituted an important developmental element and, at the same time, have given rise to major concern regarding their retention and their maintenance at a satisfactory level within this local area. In whole-country terms, this region has for almost two centuries been a statistical low point demographically, with weak natural population dynamics and insufficient inward movement of population.

Many writers (Pavel, 2000, Popa et.al., 2007, Rusu, 2007) ascribe this situation to a specifically "Banat type" demographic behaviour characterised by a low birth rate. This was borrowed from the Swabians who settled here and who influenced the indigenous population in a number of their cultural practices, including that of not producing more than one child per family (the Swabians were a large community, originating in southern Germany and in other parts of the Hapsburg Empire, who were brought to Banat as colonists from 1716-1718 onwards after its freeing from Ottoman control).

Whereas in other parts of Romania a higher birth rate was encouraged, by both external agencies – the State, the Church – in Banat, this originally Swabian custom struck deep roots, the principal motive being a wish to keep the family's possessions in the hands of only one person. In addition, during the past half-century, during which there has been substantial movement of population into Banat, this anti-natalist behaviour pattern has even spread to the incomers, who have thus not succeeded in modifying the demographic development of the region in a radical and long-term way.

However, the area we are dealing with in this study (the Western Region) also includes, besides the three counties which make up "administrative" Banat (Timiş, Caraş-Severin and Arad), the county of Hunedoara, a space which is different from Banat from the point of view of human resources, but that lies at the point where influences from Transylvania, Oltenia and, of course, Banat itself intermingle. The human resources potential of the Western Region of Romania thus starts from premises which tend to accentuate imbalances, disparities and polarities; it cannot be assigned any homogenising or uniform descriptors. Such a hypothesis is not entirely a risky one if we bear in mind the great social, political and economic changes which have come upon the Romanian society in the past six decades and that have inevitably left their mark on human resources.

Methodology

Human resources potential is a relatively new category of classification and is particularly popular in approaches with a bias towards economics. "*Human resources* refers to the totality of the people within a given space, viewed simultaneously in quantitative terms (as a number) and qualitatively (their level of competence, education, professional training, health etc.). This concept thus provides a link between the number and demographic structure of the people who make up a group, on the one hand, and their level of competence (knowledge, aptitudes, familiarity with working etc.) on the other." (Batey, 2002, 54)

Labour resources (quantitatively the most important category of the total population) is used to refer to that section of the population which possesses that combination of biological, physical and intellectual traits which makes possible their direct and permanent participation in some useful socio-economic activity (Preston et.al., 2001). Labour resources (the active element in society, engaged in production or in the service sector) are conditioned by two sets of factors: *demographic* ones, in that their volume is influenced to a major degree by demographic variables (birth rate, death rate, average life expectancy etc.), and *socio-economic* ones, since the age limits (especially the upper limit) associated with these resources can change as a function of factors that are socio-economic in nature (degree of economic development, legislation regarding the age of retirement etc.).

However, in reality it is not the case that all those capable of working are actually in employment. This is a consequence of specific socio-economic conditions, which differ widely from one state or region to another (the structure of the economy, its ability to provide jobs, the pace at which the economy is developing, the retirement age etc.), of tradition, of different levels of professional training, of the number of years normally spent in full-time education, of the proportion of the whole population who are pursuing studies of some kind, of the length of military service and the proportion of the population serving at any one time, etc. For this reason, within any population we may speak of the *active population* on the one hand and the *non-active population* on the other (Ungureanu, Muntele, 2006).

The term 'active population' is, unfortunately, quite vaguely defined. It is normally used to refer to all those who wish to work, irrespective of whether they actually manage to do so in a settled and uninterrupted way, and therefore includes those in temporary work, those providing some form of unpaid assistance, generally within the family, young jobseekers, those carrying out their military service and even the unemployed (Rowland, 2006). Nor is the non-active (provided for) population more precisely defined. In principle, those who are financially dependent on the active population – family members, retired people, school and university students etc.) – are considered to be non-active (Ulrich, 1997).

From a qualitative point of view, human resources potential is closely linked to the term development (Guest, 1997, Lecaillon, 1990, Mathur, 1999, Etzkowitz and Klofsten, 2005, Gennaioli et.al, 2013). Because, on the one hand, development with its multiple dimensions cannot be conceived of in the absence of suitable human potential, and because, on the other hand, development ought to have as its principal aim the proper satisfaction of essential human needs. The term 'human potential' is clearly not a synonym for the term 'human development', although a number of links between the two concepts do exist. The quality of human resources depends most of all on schooling and all the factors by which this is influenced, but this in turn operates in close connection with other factors such as *health* and *level of access to means of communication*. The greater the investment in education and schooling, the higher the human resources potential. Academic studies agree that the development of human resources comes about not only via the teaching provided in school but also through people learning on their own and studying on their own, and for this *the existence of some accessible means of communication* is a prerequisite (Becker et.al., 1997).

At the same time, investment in the health of the human resources is directly connected to their level of education and to access to the mass media, since an appropriate amount of medical knowledge cannot be acquired if means of communication are insufficiently developed. At a theoretical level, the logical sequence of the causal links between the three abovementioned factors shows that the higher the level of education in a region, the more developed its means of communication will be, and that the level of investment in health is higher or lower as a function of the level of communication. In practice, problems may appear when dealing with these causal links, due to an overload of available data that strains efforts at qualitative analysis. In our study we will investigate these correlations on the basis of the following sets of data: people in high school or university as a proportion of the total active population (those aged 15-59) as an index of access to schooling; number of PCs per thousand inhabitants as an illustration of access to communication; number of doctors per thousand inhabitants, an index that suggests how easy or difficult it is to access medical and health services (Pike, 2006).

Given these causal links of a conceptual nature, our analytical approach may be angled from two principal directions – quantitative and qualitative – on the basis of which arguments are the most relevant at a regional level. Among the quantitative arguments (those susceptible to statistical analysis), *the number of the population capable of working* – the human resources pool of any area of land -, *the degree to which the paid workforce is employed in service industries* and the *rate of unemployment* can reveal essential characteristics that are directly linked with the development potential of the region concerned. Alongside this, looking now from a qualitative point of view, a number of specific features can be outlined on the basis of such indicators as *the degree of training of the human resources*, their *level of access to means of communication* and *the state of their health*. Theoretical studies show that these all have a decisive impact on the growth of the human resources potential of any given geographical area (Merlin, 1997).

Results

The quantitative evaluation of the human resources of the Western Region

A limited pool of labour resources

Although the focus of our study is on the recent period (1998-2014), it is useful to be aware of the context within which the volume of labour resources rose and fell at a national level in the first decade after the events of December 1989. This background picture was characterised by a brief period of growth in labour resources until 1992, followed by a substantial decrease almost up to the beginning of the new millennium, when the balance was redressed. This situation can be explained as the result of phenomena that are well known: a decrease in Romania's overall population, demographic ageing and an upward trend in emigration. Although the level of labour resources in the Western Region has fluctuated, it does display a number of characteristic stages which are to a large degree the effect of the economic and social phenomena that have shaped Romania in the last few decades (fig. 1). In absolute terms, the volume of labour resources shows a generally decreasing trend until 1994; this corresponds to the period of falling population and severe economic recession that Romania experienced in the 1990s. The 1994-2002 period shows a fluctuating volume of labour resources; this stage covers the years when Romania was transitioning to a market economy and also takes in 1998, the year when large numbers of the workforce began to emigrate. The appreciable growth seen over the 2002-2014 period, although averaging only 5% at a regional level, is explainable in terms of a bulge in the adult age group accompanied by a fall in the numbers of children and young people, due, obviously, to a fall in the birth rate and a reduction in natural vigour.

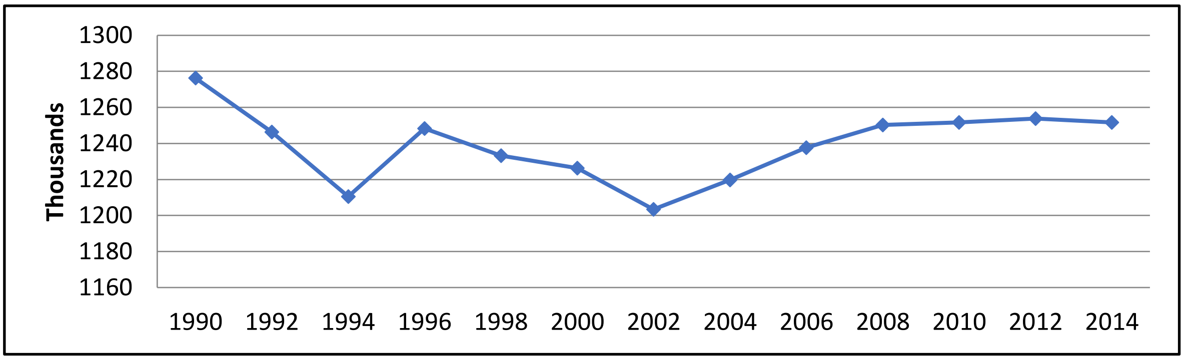

Fig. 1: The evolution of labour resources in Western Region (1990-2014)

(Source: National Institute of Statistics)

Although a certain amount of imprecision is involved, knowing what proportion of the total population of a defined area is formed of potential working population (labour resources) can provide a reasonably accurate picture of the extent to which that area is well supplied with labour resources. According to the definitions used by demographers, what is regarded as the potential working population is the population aged between 15 and 59 – the ages which, broadly speaking, indicate when a person joins the labour force and when they retire. Figure 4, which shows the distribution of the potential working population according to where people live, demonstrates that the largest reserves of human resources are concentrated in the urban parts of the region (the towns of Timişoara, Arad and Reşiţa in particular), followed by a relatively compact area that comprises the flatter country parts of Arad and Timiş counties. The hilly/mountainous areas of each county are the most lacking in terms of their volume of labour resources.

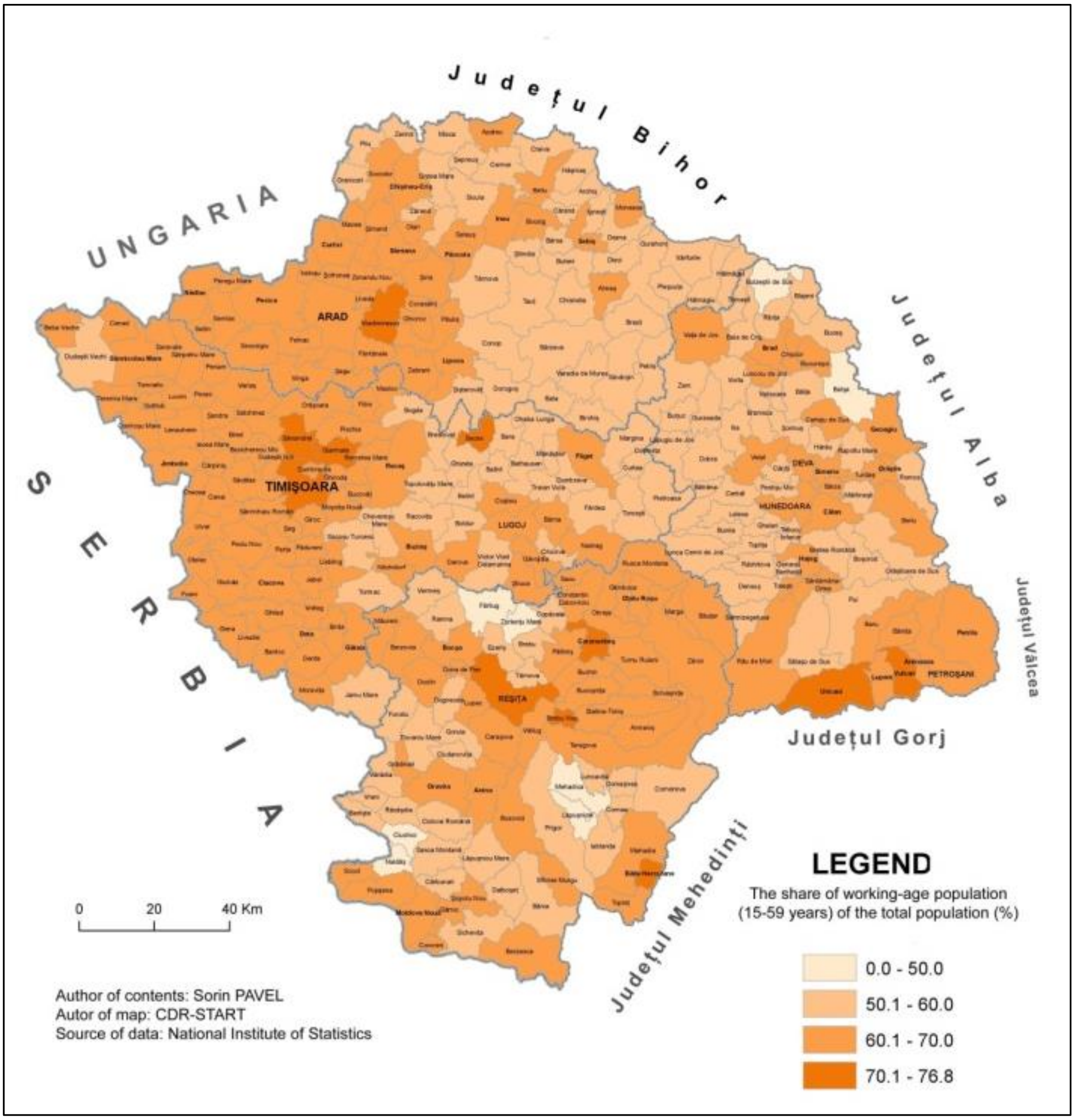

Fig. 2: The share of working-age population (15-59 years) of the total population in the Western Region

The qualitative evaluation of the human resources of the Western Region

Data from table 1 and figure 3 indicate that counties where a higher proportion of the population is in school also have more developed communications. While it might have been expected that the city of Timişoara, through its status as one of Romania's major university centres, would give Timiş a high ranking in the proportion-of-population-in-school table, Arad comes as a surprise, ranking second within the region, but far ahead of Hunedoara and Caraş-Severin counties. Arad's exceptional position in terms of education and communication could give rise to interesting hypotheses about the origins of the 'tides' of human resources that flow towards the two regional hubs (Timişoara and Arad) and the qualitative distinctions between them.

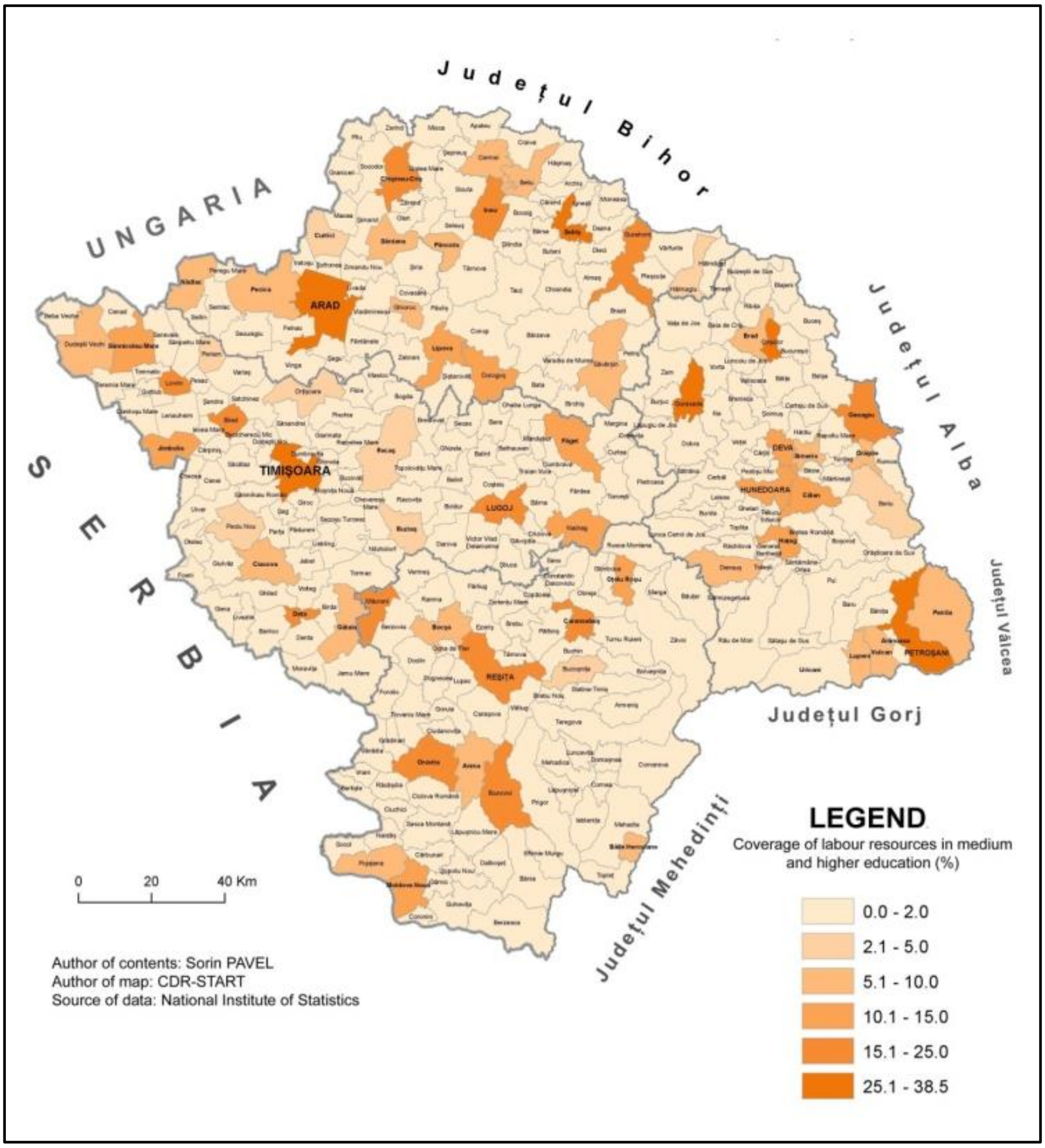

Fig. 3: Coverage of labour resources in medium and higher education

The other two counties, Caraş-Severin and Hunedoara, follow the same sequence of correlation as regards the indicators under consideration, with the one exception that Hunedoara is ahead of Arad in terms of access to healthcare. Why does healthcare not follow education in this case? The answer is not far to seek if we appeal to other variables such as the degree of urbanisation, higher in Hunedoara county than in Arad county, it being well known that medical personnel are more concentrated in urban areas. Settlement by settlement (fig. 12), the highest proportions of population in school are naturally found in university centres (Timişoara and Arad), followed by county towns, smaller urban centres and finally main villages that have high schools.

Table 1: Qualitative indicators of the human resources in Western Region

Indicators (2014)	Arad	Caraş-Severin	Hunedoara	Timiş	Western Region
Number of physicians (‰)	2,7	1,9	3,0	5,7	3,7
Number of PCs (‰)	11,9	9,9	10,5	17,2	13,0
Proportion of school population in total population (15-59 years) (%)	14,6	9,5	10,6	18,2	13,9

Source: National Institute of Statistics, 2014

Discussion

The variables taken into consideration above are relevant at the regional level to the extent of which the social mechanisms through whose agency they come about can also be identified. This is, of course, a matter of the cumulative effects of lifestyle, the way in which the development of the private sector is achieved, the correlation between the distribution of scarce resources within society, education etc. At the same time, it should be emphasised that the development of human resources is strongly linked to the material capital each county has at its disposal, and the level of healthcare and educational provision is in direct proportion to this. In the case of the Western Region, as elsewhere, the poorer counties (Caraş-Severin and Hunedoara) are the ones with a lower quality of human resources, which implies a degree of dependence of the development of human potential on the existence of material resources.

Bringing together the data analysed, we may draw the conclusion that the human resources potential of the Western Region is limited in nature but exhibits multi-dimensional disparities from both a quantitative and a qualitative point of view. The administrative boundaries which divide up the region delimit territorial units which have a surplus of human resources but where these are insufficiently developed and structurally imbalanced (Hunedoara county), others with a limited amount of high quality human resources and a high potential for attracting human resources from other areas (Arad and Timiş counties) and one case of a territorial unit whose human resources are both insufficiently developed and lacking from the quantitative point of view (Caraş-Severin county). Identifying the spatial disposition of human resources potential can be a useful jumping-off point for the planning of regional policy, which in order to achieve its main objective, the reduction of disparities in development, will need to take into consideration, among other factors, the disadvantages that stem from the underuse of human potential on the one hand and from overestimating it on the other.

Conclusion

The distribution of human resources potential within the Western Region cannot be uniform for so long as the boundaries of this unit of territory contain within them historical spaces that have evolved in different ways over time, each with its own demographic, social and economic personality. Often, however, boundaries within the region follow the lines of force of the distribution of human potential, and the quantitative and qualitative characteristics of this potential constitute the foundation of the entire edifice of regional social differentiation. There is strong empirical evidence to show that it is educational level that to a large extent determines access to healthcare and the possession of means of communication. From a quantitative point of view, however, the region's labour force reserves are limited. Since its internal labour surpluses are for the moment unable to relocate, movement into the region from outside will be required in the future in order to meet the needs of any sustained development. Redeploying the region's own underemployed human resources (found in Caraş-Severin and Hunedoara counties) is no easy matter; it would require either large-scale retraining of the workforce or the deliberate siting of industrial enterprises in areas that are not attractive from an investment point of view.

References

Batey, P., 2002: Human Resources and Regional Development, in: Regional Development Reconsidered, Springer Berlin Heidelberg.

Becker, B. E., Huselid, M. A., Pickus, P. S., & Spratt, M. F. (1997). HR as a source of shareholder value: Research and recommendations. Human Resource Management: Published in Cooperation with the School of Business Administration, The University of Michigan and in alliance with the Society of Human Resources Management, 36(1), 39-47.

Gennaioli, N. & all, 2013: Human Capital and Regional Development, in: The Quarterly Journal of Economics, 128(1). DOI: 10.1093/qje/qjs050

Guest, E., D., 1997: Human Resources Management and Performance : a Review and Research Agenda, in: "The International Journal of Human Resources Management", volume 8, issue 3. DOI: 10.1080/0958519973.

Lecaillon, J.-D., 1990: Démographie économique. Observation, analyse, interprétation, Litec, Paris.

Mathur, K., V., 1999: Human Capital – Based Strategy for Regional Economic Development, in: Economic Development Quarterly, volume 13, no. 3. DOI: 10.1177/089124249901300301

Pavel, S., 2000: Comportamentul urban şi climatul urban în Timişoara [Urban Behaviour and the Urban Climate in Timişoara], in: Regionalism and integration. Culture, space, development, Brumar, Timişoara.

Pike, A., 2006: Local and Regional Development, Routlege, New York.

Popa, N. & all, 2007: Banatul: identitate, dezvoltare, colaborare regională [Banat: identity, development, regional collaboration], Mirton, Timişoara.

Preston, S. H., & all, 2001: Demography: Measuring and Modeling Population Process, Blackwell, Oxford.
Rowland, D., 2006: Demographic Methods and Concepts, Oxford University Press.
Rusu, R., 2007: Organizarea spaţiului în Banat [The Organisation of Space in Banat], Mirton, Timişoara.
Ulrich, D., 1997: Measuring Human Resources: and Overview of Practice and a Prescription for Results", in: "Human Resource Management", Fall 1997, volume 36, no. 3.
Ungureanu, Al., Muntele, I., 2006: Geografia populaţiei [Population Geography], Sedcom Libris, Iaşi

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