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# Risk of Dynamics of the River Stream in Tectonic Areas. Case studies: Curvature Carpathian - Romania and Maghrebian Chain - Algeria

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## Abstract

The tectonic characteristics of the Alpine orogeny highlight some similarities in the genesis of landforms over large areas. This paper analyses the role of tectonic processes in two subsiding areas with uplift movements. The overall tectonic activity implies the formation and evolution of the hydrographic network and its correlation with the major relief structure, thus forming streams parallel to the high-altitude lines, as well as consistent, transversal, and subsequent streams.
These tectonic processes are accompanied by antecedents and/or epigenesis common in the Eastern Carpathians, Romania. Hence the Bistrița River is longitudinal compared to the Bistrița and the Stânișoara Mountains, but also transversal in other sectors. In Algeria, the Northeast, especially the Zighoud Youcef zone (NE of Constantine), is characterized by a particular morphography and morphometry of the river basins which reveals reorganizations of the river network through their transversal or longitudinal characteristics compared to the structure and tectonics of the region. In areas with imminent catchments, the regressive erosion amplifies the slope dynamics and slope processes vulnerability.
The uplift and subsidence movements impose reorganizations of the hydrographic network of the catchments with the alternation of the erosion and sedimentation processes it creates a certain fluvial style pattern. In the subsidence of the Întorsura Buzăului depression, the longitudinal profile of the Buzău River has a very low slope and its meanders create islets. This is subject to frequent floods which imposed the riverbed regularization. However, in Zighoud Youcef, the Oued Smendou River also indicates some similarities with the Buzău River structure due to subsiding areas of the Mila-Constantine basin.

**Keywords:** *tectonic risk, Alpine orogeny, river network, Constantine region, the Atlas, The Curvature Carpathians*

## Rezumat. Riscul dinamicii cursurilor râurilor în ariile tectonice. Studii de caz: Carpații de Curbură (România) și lanțul Maghrebian (Algeria)

Caracteristicile tectonice ale orogenului alpin permit evidențierea unor similitudini în geneza formelor de relief pe spații extinse. Lucrarea analizează rolul manifestărilor tectonice în două arii subsidente și tectonic pozitive. Tectonica de ansamblu impune formarea și evoluția rețelei hidrografice în raport cu structura majoră a reliefului; astfel, se formează: cursuri paralele/ longitudinale cu linia marilor înălțimi si cursuri transversale/subsecvente. Procesele sunt însoțite de antecedente si/sau epigeneze, frecvente în Carpații Orientali. Astfel, râul Bistrița este longitudinal fata de Munții Bistriței si Munții Stânișoara, dar și transversal în alte sectoare. În Algeria, Atlasul de nord-est, în special zona Zighoud Youcef (NE de Constantin), se caracterizează printr-o morfografie și morfometrie particulară a bazinelor hidrografice, care dezvăluie reorganizările rețelei fluviale prin caracteristicile lor transversale sau longitudinale în comparație cu structura și tectonica regiunii. În zonele cu captări iminente, eroziunea regresivă amplifică dinamica pantei și vulnerabilitatea proceselor de pantă.
Mișcările de înălțare și mișcările subsidente determină reorganizări ale rețelei hidrografice prin captări, alternanța proceselor de eroziune și acumulare și deci crearea unui anumit tipar fluvial. In depresiunea Întorsura Buzăului, profilul longitudinal al râului colector are o pantă foarte mică, favorizând procesele de meandrare și crearea ostrovelor. Ca urmare a riscului inundațiilor, s-au întreprins ample lucrări de amenajare a albiei minore. In arealul Zighoud Youcef, râul Oued Smendou indică, de asemenea, unele asemănări cu structura râului Buzău datorită zonelor de subsidență din bazinul geologic Mila-Constantine.

**Cuvinte-cheie:** *risc tectonic, orogeneza alpină, rețea hidrografică, regiunea Constantin, Munții Atlas, Carpații de Curbură*

## Introduction

The vulnerability to the active tectonic processes indicates a tectonic risk with environmental and societal consequences. These risks are usually analysed as geomorphological, geological and hydrological, according to the environment and the main exogenous agents (relief/gravity, water/floods, soil/erosion, etc.). In order to study those risks, it is very important to know the geological, tectonic and paleo-evolutionary characteristics, including the paleoclimatic factors of the study area to predict the triggering factor and the dynamics of the extreme hazardous processes. This paper analyses the principal role of the tectonic processes significant for triggering a risk in both areas of interest of the Alpine orogeny, the Carpathian and the Mila-Constantine basin. Alpine orogenic regions require comparative studies due to tectonics and structure reflected by the arrangements of peaks influenced by active uplifting movements in addition to the presence of depressions with subsiding movements (Ciccacci et al., 1999; Benabbas, 2006).

The overall tectonics involves the formation and evolution of the hydrographic network in relation to the major structure of the relief, against the general background of the Quaternary climate fluctuations (Piacentini and Miccadei, 2014; Piacentini et al., 2015). Thus, parallel watercourses to the line of great heights (consistent) and transversal watercourses (subsequent) are formed. In general, the transversal watercourses formed by antecedents are well highlighted on the physical map of Romania (Fig. 1) (Naum 1961, Grigore 1989, Orghidan 1939, Posea 2005).

The processes are followed by antecedents and/or epigenesis, common in the Eastern Carpathians. Thus, the Bistrița River is longitudinal compared to the Bistrița and Stânișoara mountains while transversal in other sections (Donisă 1968, Săndulache 2007) (Fig. 2 B).

In the north-east of Algeria, it is necessary to take into consideration the heritage and the geological history to explain the formation and the evolution of the relief, thus, the Rhumel and the Ben Brahim-Bouhadjeb and Smendou rivers are longitudinal compared to the Numidic chain while transversal in other sections.

However, the north of Algeria is characterized by a varied and complex geological and geomorphological context, distinct by a strong tectonic and an active seismic activity (Benabbas, 2006; Yelles-Chaouach et al., 2006; Benzid, 2017). The Mila-Constantine basin in north-east of Algeria, is more susceptible to landslides and floods hazards than the other parts of the country which is presented by the record of many important events (Bourenane et al., 2014, 2016; Manchar et al., 2018 Manchar et al 2019). These phenomena become more complex where the impact of the hydrogeomorphic hazard evolve in space and time (Hamadou and Amireche, 2018).

Based on field research and bibliographic documentation, applying multicriteria geomorphological methods as well as GIS techniques, this paper highlights two cases: 1) the dynamics of a representative river from the Curvature Carpathians – the Buzau River. 2) the characteristics of the drainage network related to the morpho structure and tectonics in the north-eastern part of Algeria (Constantine region). The analyses of the vulnerability of rivers to extreme natural processes, initially due to tectonic processes (Benabbas et al., 2017). Morphotectonic and morphostructural risk is the result of active tectonics that creates a typical landscape that attests to the degree of danger (Dramis F, Cliff Oliver 2016) However, this argument is particularly useful in establishing the long-term effect of anthropogenic actions in the slope and river (dams, bridges, skiing... etc.) (Teodor 2013; 2017). The alpine regions create a topographic contrast between mountain peaks and depression basins even in mountain regions of medium altitudes (Raffy Jeannine 1983; Peulvast J-P et al. 2013).

The dynamics of the rivers is seen in a hydro-geomorphological context, of the synergistic relations between the river/water and the topographic/relief surface (Ballais et al., 2011, Grecu et al., 2017b; Arseni et al., 2019, Sembroni et al. 2021). Precipitation and changing climatic conditions increase runoff variability and control its evolution, which have a major impact on hydro-geomorphological hazard. That, in turn, may explain the intensity of some tectonics and flood events (Meddi et al., 2009; Waleed A 2021).

## Study area – vulnerability factors

### Romanian Carpathians

The Romanian Carpathians, or South-Eastern Carpathians (according to Mihăilescu, 1963), are the highest Alpine mountains in Europe (about 1500 km between the Vienna Pass and the Timok River) (Institute of Geography, Geography of Romania 1987). On the Romanian territory, the orogenic, geological and morphological elements determined the separation of the subunits (Fig. 1A and 1B).

The Eastern Carpathians (including the Curvature Carpathians) with a maximum altitude of 2303 meters in Pietrosul Rodnei peak, characterized by approximately parallel peaks, volcanic (Neogene volcanism in the west (Fielitz and Seghedi 2005), crystalline (center) and sedimentary (East); the Southern Carpathians (mainly crystalline schists, limestones and conglomerates towards the limits of the massif, with a maximum altitude of 2545 meters in the Moldoveanu peak and the Western Carpathians (maximum altitude of 1849 meters in Cucurbăta Mare peak, Biharia Massif) characterized by the presence of old volcanism, crystalline in high massifs (Mesozoic sedimentary). The name of the mountain sectors is considered by the position within Romania, but also towards the Transylvanian sedimentation basin, from the central part, a hilly plateau with slight subsidence movements. The hydrographic network was formed in different stages, taking into account the arrangement of mountain peaks, the ratios to baseline levels, climatic conditions (Posea, 2005), also depending on the capture, epigenetics, antecedents, erosional and cumulative have finalized the morphology of the rivers and implicitly of the hydrographic basins, so that today it presents a quasi-circular aspect compared to the Romanian

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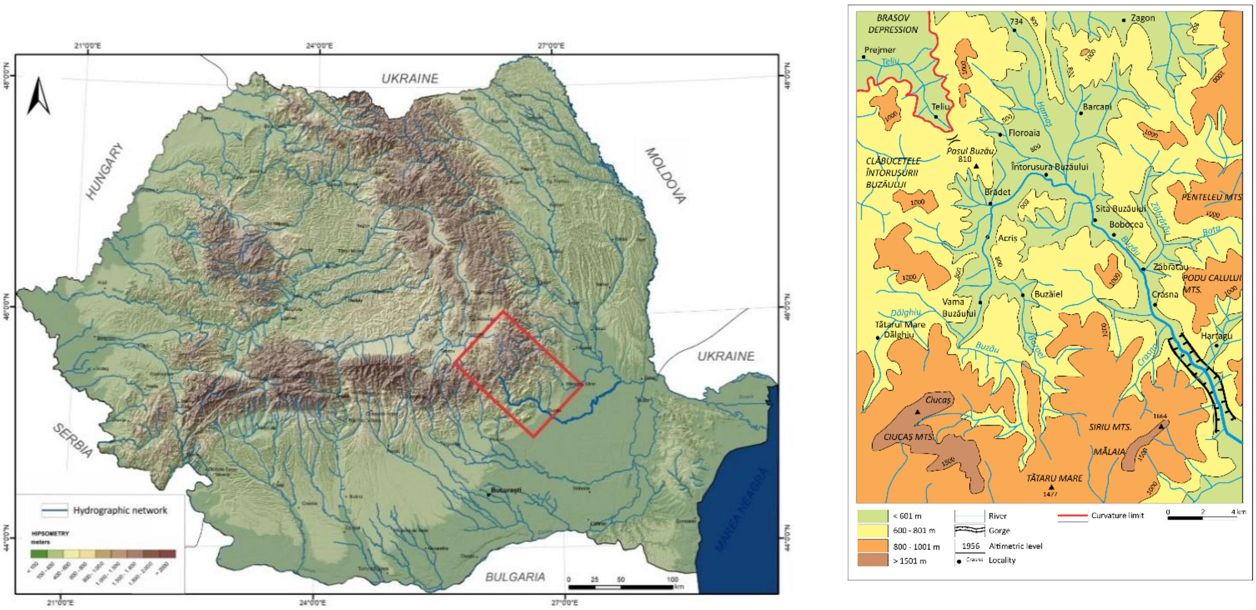
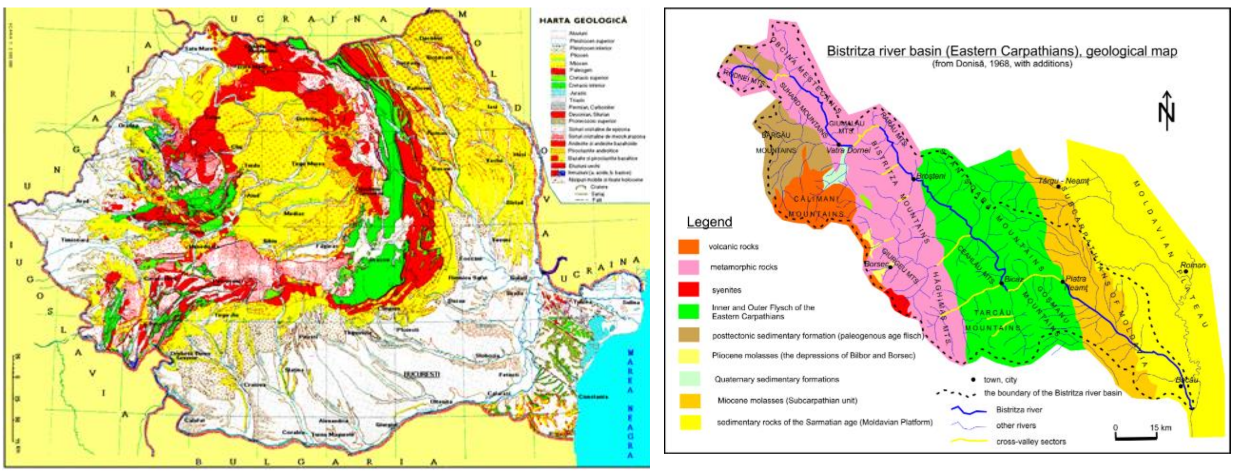
Carpathians system (Posea et al., 1974). Some of the most complex genetic aspects are presented by the rivers of the Eastern Carpathians (Fig. 2A).

The Romanian Carpathians are an arcuate chain of mountains, formed in response to the continental collision between the European Plate and several microplates during the Alpine Orogeny (Schmidt et al., 1998; Mațenco and Bertotti 2000, Tarapoanca et al. 2003). The main depocenter in the Carpathians foredeep is the Focşani Depression, where subsidence continues up to present time. During the Pliocene–Quaternary, the western flank of the Siret subsidence region (Focşani depocenter) was tilted as a consequence of the uplift of the neighbouring Carpathian chain (Necea et al., 2005; Mațenco et al., 2007; Necea 2021). Its opposite important regional vertical movements: the uplifting chain and subsiding foredeep (about +/-5 millimetres per year; (Zugrăvescu et al., 1998) at less than 100 km in distance (Fig. 3). It is also characterized by the outcrop of rock types susceptible to erosion: sand, clay, conglomerate and marls that record the change from a marine to fluvial-lacustrine environment (Molin et al., 2012; Teodor et al., 2014; Teodor and Dobre, 2015).




**A** **B**

**Fig. 1: A) Geographical position within Romania and large geographical units; B) Upper Buzău and Întorsura Buzăului Depression - physical-geographical map**




**A** **B**

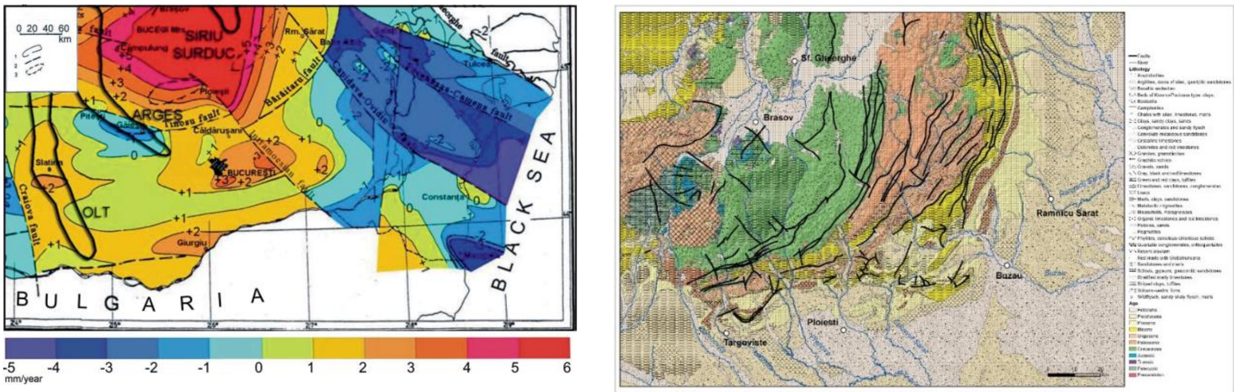
**Fig. 2: Geological maps of Romania. Carpathian orogeny units and the hydrographic network in the central part of Romania (A) and geological structure (B); the longitudinal and transversal character of the rivers in the Eastern Carpathians - the Bistrița basin**

The complex and orderly structure, in rows arranged on the north-south direction (from east to west – sedimentary, crystalline, volcanic), separated by large depressions, is the main factor in deciphering the hydrographic network, in which the longitudinal sections alternate with the transversal ones. The southern part of the Eastern Carpathians presents an arch of the sedimentary ridge (the crystalline and volcanic series are missing) with its own morphological structure, imposed by the Black Sea microplate (Posea, 2005).

In the Curvature Carpathians, the recent vertical crustal movements (elevation-subsidence at short distances), the existence of the most active epicentral area for earthquakes in Romania and continental Europe, the relief modelling and the evolution of the hydrographic network are made according to their own patterns (Grecu, 2016) (Fig. 3A).

The morphological complexity of the Curvature Carpathians also imposes itself on the external marginal relief (Grecu, 2010). The contact area between the Sub-Carpathian and the Romanian Plain is represented by a piedmont belt (glacis-like, macro-landform associated with the monocline), traditionally considered a part of the Romanian Plain because of its very gentle slopes. The subsidence of the Romanian Plain coupled with the Carpathian and Sub-Carpathian uplift induced a regional base level, lowering that allowed the generation of fluvial terraces and entrenched alluvial fans interacting with the Quaternary climate changes (Grecu and Sacrieru 2009; Grecu et al., 2007, 2010; Grecu et al., 2014). The element of complexity is also due to local tectonic features (Necea, 2021), like the anticlines relative to the so-called "Wallachian" phase (Săndulescu, 1988).

These regional features have an influence on rivers crossing the Curvature area. Several rivers of this area have concave and steep longitudinal profiles and they are in a transient state of disequilibrium as a consequence of a more recent emersion of the Curvature Carpathians (Badea and Niculescu, 1964; Molin et al., 2012). Moreover, other previous studies showed that these rivers have the highest suspended sediments loads in Romania (up to 25 tons per hectare per year) (Mociorniţă and Birtu, 1987 cited by Zaharia et al., 2011; Dumitriu, 2020).




A B

**Fig. 3: A) Recent vertical crustal movements map of South-Eastern Romania (after Zugrăvescu et al. 1998). Legend: 1 – seismic lines (mm/year); 2 – active crustal faults; 3 – areas affected by diapirism; B) Curvature Carpathians – geological map (data processed from the 1: 200,000 vector geological map)**

## Buzău River – river formation, vulnerability factor

The Buzău River springs from the Carpathian flysch, the northern mountain side of the Ciucaș Mountains, from an altitude of approximately 1800 meters, having a south-north direction. From the source area, to the confluence with Acris (about 20 km), the river follows a geological contact between the less resistant and conglomerate Cretaceous formations with a slope of over 60 m/km to the confluence with Strâmbu, 14 m/km at Vama Buzău (State Geology Committee. Geological map, Covasna sheet 1970). From Acris the river is oriented to the northeast enters the tectonic-erosive depression, where the slope of the river is reduced, about 4-4.5 m/km the accumulation processes lead to the formation of islets and frequent floods. Approximately from the city centre, it is oriented to the South-East and then to the South (with local modifications). The river basin, covering an area of 5264 km$^2$, develops within the Curvature Carpathians and the Curvature Sub-Carpathian, and within the Romanian Plain. It flows into the Siret River with a length of 334.4 km (Uivari, 1972). The longitudinal profile presents sections, with varying intensity of the relations

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between erosion and accumulation (Fig. 12) influenced by the relations with the slopes (in the plain at Bănița at 0.7 m/km) (Minea, 2011).

Within the mountain area of the Buzău River, there are differentiated five sectors (Grecu et al., 2017 a; Grecu et al., 2018):

1. Întorsura Buzăului sector (between Buzău-Afiniș junction, (Brădet settlemnet) and Sita Buzăului village) is distinguished by the active dynamics of the river bed and by hydrotechnical works against floods, regularization of the minor river bed and shore defence (Fig. 4A and 4B);

2. Northern Transcarpathian section (between Sita Buzăului and the Buzău-Harțagu junction (partly Buzău Gorge, corresponding to the line of great heights);

3. The internal southern Transcarpathian sector (Harțagu/Băile Siriu – Siriu village, including the Rockfill Dam);

4. External Transcarpathian – Sub Carpathian sector located between Siriu village and downstream of Păltineni, at the entrance into the Sub-Carpathians.

A B

**Fig. 4: A) Minor River bed with river deposits at Brădet (Întorsura Buzăului); B) The transverse valley of the lip in the Harțagu gorges**

The Buzău River was formed during successive stages, with specific morphologies, in correlation with the geological and tectonic aspects of the Curvature Carpathians. The most discussed stage is related to the bend formed by the Buzău at Întorsura Buzăului and therefore the change of flow direction towards it (Orghidan, 1969; Posea and Garbacea, 1959; Posea, 1971, 2005).

Here, we address the following issues:

1) The problem of the transversal course;

2) Formation of the course between spring and Bradet (confluence with Acris);

3) The course of the river within the Întorsura Buzăului Depression.

The rivers from the Curvature Carpathians are transversal rivers, some bypass the line of the great heights (see the geological map and the physical map). The Buzău River forms in the line of the great heights (Siriu-Penteleu) a narrow valley type key between the confluences with Crasna and Harțagu. In fact, the morphological characteristics, the alternation of basins with narrow sectors, the analysis of the longitudinal profile and the analysis of the levels (Nordon, 1933) are arguments in the antecedent formation of the Transcarpathian Buzău (Orghidan, 1969; Posea, Garbacea, 1959; Posea 1971, 2005). This aspect is also reflected in the dynamics of the slopes, the activation and/or reactivation of the slope processes (landslides, erosion).

The upper lift and the watercourse of the Întorsura Depression are influenced by the tectonic movements – subsidence in the bottom of the depression, of the rise in the southern part on the line of the great heights and by the geological structure (Orghidan, 1939; Naum, 1961; Posea, 1971, 2005; Ielenicz, 1984; Grigore, 1989). Upper Buzău, Bâsca Mare and Bâsca Mica developed their basins over the current line of high altitudes, the evidence being the erosion surface of +/-1000 meters. According to Orghidan (1969 p. 43), there are no traces to prove that Buzău river is a late intruder.

The organization of the drainage network was done differently as claimed by some authors, and their opinions must be taken into account when considering the different stages in the evolution of the river. Thus, the influence that the lower base level of the Brașov Depression had on the disorganization of a paleo-network is accepted. The first stage refers to the existence of a paleo-Buzău with springs in Harghita, over the Brașov Depression (Posea and Garbacea, 1959), and explains a paleo network with the right tributary of the Upper Buzău in Ciucaș. The subsidence in the Turn Depression determined the concentration of the hydrographic network towards a local level, and then the reorganization according to the game of the basic levels and of the Quaternary tectonic movements (Iancu, 1971; Ielenicz, 1984). In our opinion (Grecu), the oscillations of the riverbed on a river-lake subsident relief imposed a gradual direction of the flow to the south on easy lines. The Buzău Valley corridor is located on an axial sinking area of the folds, it is a tectonic corridor (Socolescu et al., 1975).

Along the corridor, there is an alternation of narrow transverse and diagonal sections, created in the Miocene and the Pliocene and also elongated depressions corresponding to synclines. This orientation is still observed in the dynamics of the riverbed. The analysis of meanders (1980 and 2017) from the source to the confluence with Crasna shows changes by sectors as follows (Grecu et al 2021):

- In the upper watercourse (up to Brădet), the meandering index increases from 1.35 in 1980 to 1.4 in 2017);
- In the depression area (between Brădet and Sita Buzăului), the lateral erosion is the most active, the meanders with variable lengths are bigger and more numerous, some of them have not been maintained; the meandering index increases in 1980 to 1.46; in 2017 it remains the same, but decreases compared to 1980 to 1.4;
- Downstream, towards the confluence with Crasna, the meanders are dense but of much smaller lengths (coefficient in 1980 and in 2017 of 1.26).

Overall, from the source to the confluence with Crasna, the meandering index decreases, but it has higher values in the central part of the subsidence area. The transverse profiles highlight the leftward movement of the active area.

Thus, for 1980, the largest meander displacement is 2263.02 meters to the left in the upper sector I (up to Brădet ), 1079.9 meters to the left in sector II depression and 667.70 meters to the left in sector III Zăbrătău-Crasna (upstream of the gorge). For 2017, the largest shift of meanders compared to the asymmetry of the river is also to the left and is 2161.59 meters in sector I, 1078.81 meters in sector II and 667.66 meters in sector III, but there are slight decreases in values due to regularization of watercourses. Higher displacement values can be attributed to local petrographic conditions, in conditions of a lower sinuosity index.

## Geomorphological and geological settings of Mila-Constantine Neogene basin

The area concerned by this study is located within the Mila-Constantine Neogene basin. It is part of a group of intramountain basins that characterize the Alpine chain of North-East of Constantine which was mainly structured during the Tertiary phases as a result from the structuring of the Maghrebids Basin and its African and European margins (Benabbas, 2006). It is a post-nappe basin that has been filled by a silico-clastic and carbonate series of Mio-plio-quaternary age (Vila, 1980; Coiffait, 1992). This receptacle is installed on a substratum pre-structured by thrust sheet units of the Tellian, Penitellian and neritic units belonging to the external zones of the Maghrebian chain of eastern Algeria (Vila, 1980; Wildi, 1983).

Our study area is located on several distinct paleogeographic and structural domains: internal domain, Flysch domain, and external domain. The Maghrebian chain is an Alpine segment characterized by the accumulation of large thrust sheets with south vergence (Benabbas, 2006).

The altitude ranges from 500 to 1200 meters above sea level. This area is characterized by a dense hydrographic network constituted by a set of oueds (rivers), ravines and gullies This network is mainly represented by the following oueds: Oued Smendou located in the Kébir Rhumel-Smendou watershed, which is the principal stream in the basin (Fig. 5), and Oued Benbrahim-Bouhadjeb located in the Safsaf watershed (Fig. 5), and Oued El Kram, and Oued El Aria in the east which has permanent flow. Often, these streams are flowing to the Northeast direction.

The study area is characterized by a semi-arid climate with high temperatures (from 28 to 41°C) and low precipitations (from 600 to 900mm) in the summer, and high humidity, precipitation and low temperature in the winter. We can speak of two typical seasons (rainy and dry) that stand in contrast. About 63% of the annual rainfall quantity is concentrated between December and February each year. (Benzid, 2017; Manchar, 2021)

At the orographic level, the study area can be subdivided into three distinct natural sub-areas: the first one is the mountainous massifs of the Numidian chain in the north, the second one is the hills of Conde Smendou and Zardezas with altitudes varying from 400 to 500 meters and the third one is the low areas which are represented by:

1. The depression of Oued Beni Brahim-Bou Hadjeb, which drains a large part of the southern part of our study area and seems to follow a West-East direction at the beginning to change to a South West - North East, and finally to reach the valley of Oued Safsaf (beyond the mountains of Ouled Hababa) (Fig. 5, 7);
2. The depression of Oued Smendou which in its upstream part Oued Smendou is presented as a geomorphological, hydrographic, and geological (tectonic anomaly), indeed, this Oued was supposed to converge on Oued Beni-Brahim – Bou Hadjeb to join Oued Safsaf, however, it suddenly changes direction to the south of the town of Zighout Youcef forming a perfect angularity and takes a north-east south-west direction to join Oued Rhumel-Kébir (Fig. 8, 9). (Benzid, 2017; Benabbas et al., 2019; Benabbas et al., 2021).

The slopes that constitute the Mio-plio-quaternary filling, are juxtaposed on several kilometres and are

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composed of formations with clay predominance (Raoult, 1974).

From the morphological point of view, the basin of Mila-Constantine is divided, from west to east, in three units – Ouled Kebbeb, the Smendou unit that is analysed in this work, and the Mila unit, which is the most important. These units are inserted between the Numidic chain in the north and the mountains of Constantine in the south (Fig. 9).

Geologically, the study area is characterized by superposition of thrust sheet units made up from the base to the top (Fig. 6) by: Neritic unit (Cretaceous carbonate), Ultra-Tellian unit (Cretaceous-Eocene marls and marly limestone), Tellian s.s. (sensu-structo): Marly dominance (Cretaceous-Eocene), Numidian unit with sandstone Burdigalian, clay and flysch (Eocene), Mio-Plio-Quaternary: sandy clays, marls and conglomerate (Mio-Pliocene). Alluvial terraces and lacustrine calcareous formations with Quaternary age (Raoult, 1974; Coiffait and vila, 1977; Coiffait, 1992; Vila, 1980). This edifice was deposited during paroxysmal compressional phases Eocene and Miocene (Durand-Delga, 1969; Raoult, 1974).

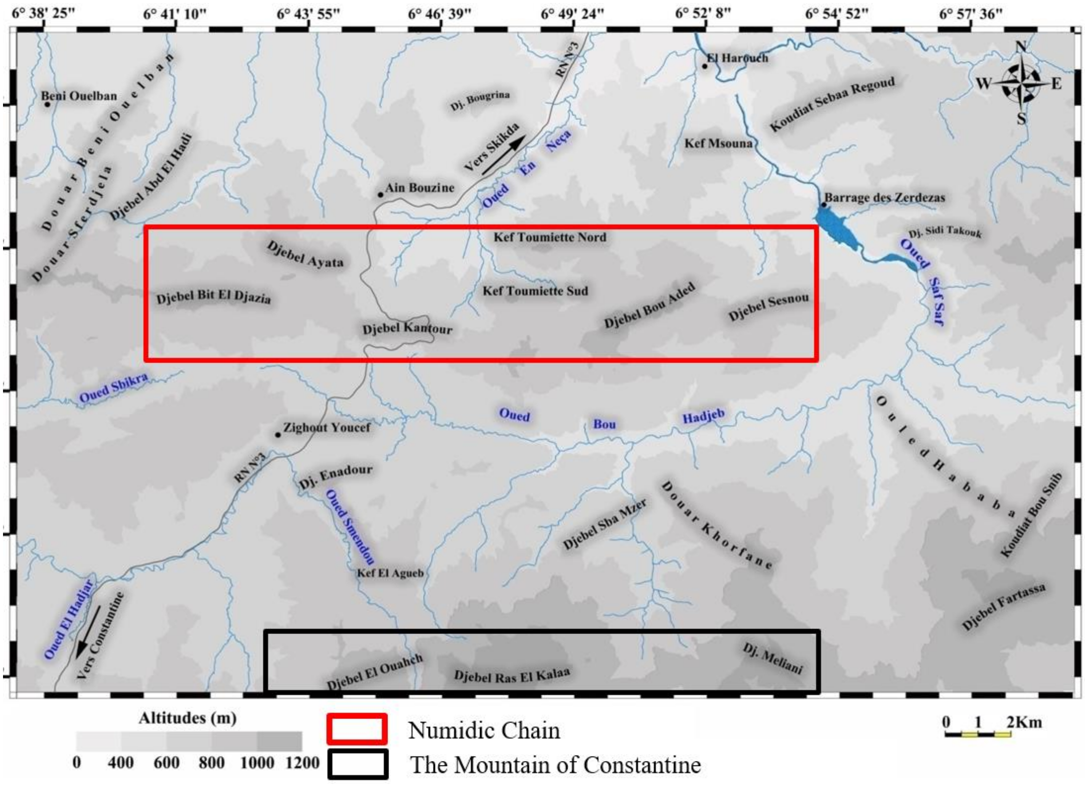


**Fig. 5: Oro-hydrographic and toponymical map of the study area. (After BENZID Y, 2017 modified)**

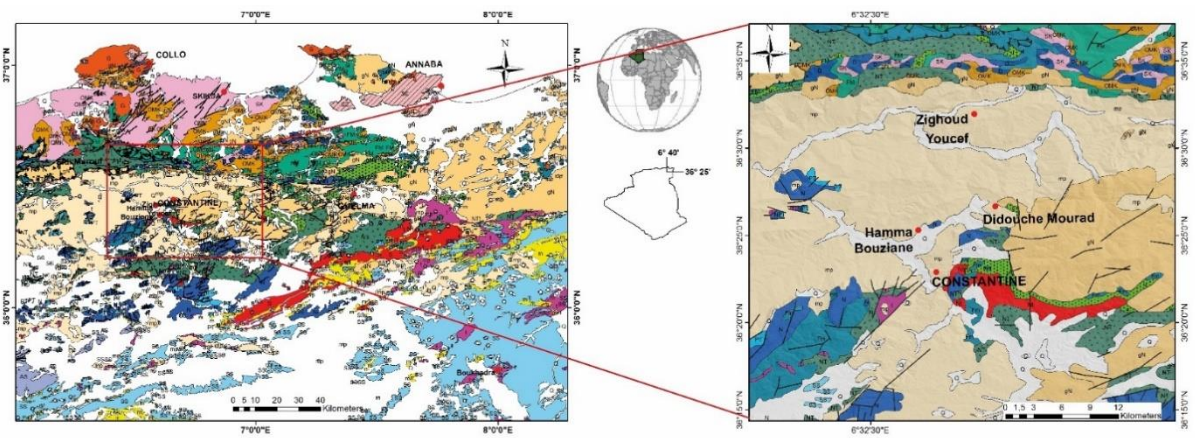


**Fig. 6: Geological position of the area study (Q: Quaternary undifferentiated (Villafranchien to current); AS: Allochthonous South Sétifien group; D: Limestone chain: Paleozoic to Upper**

**Lutetian of the internal, median and external zones; FM: Mauritanian flysches; Fm: Massylian flyschs, Typical series with phtanites or green and red breccias; G: Granite, granodiorite, microgranite, dolerites and rhyolites; N: Contantine neritic tablecloth; NT: S.S tellian tablecloths; Nt: Tellian tablecloths; OMK: Kabyle oligo- Miocene, olistostrome; P: Marine Pliocene of coastal areas; PT: Penile tablecloth; S: Allochthonous Sellaoua-type training; SB: Basic base of Cap Bougaroun (peridotites and retromorphosed kinzigites); SE: Pedestal of Jebel Edough; SK: Metamorphic base of Little Kabylia and Bou Hatem (phyllades, mica schists, porphyroids, gneiss); SS: Allochthonous and parautochthonous foreland formations; TB: Effusive rocks; gN: Numidian sandstone and mixed series; m: Undifferentiated transgressive marine Miocene of the tellian aquifers and of the allochthonous, parautochthonous foreland; m': Upper Burdigalien –Langhien of the littoral margin; mp: Continental Mio- Pliocene; t: Triassic (Clays, ground gypsum and calcaro-dolomitic ice cubes); u: Ultra-telliene tablecloth - Typical series (Neocomian to Upper Lutetian) marly and marl-limestone to light Cretaceous)**

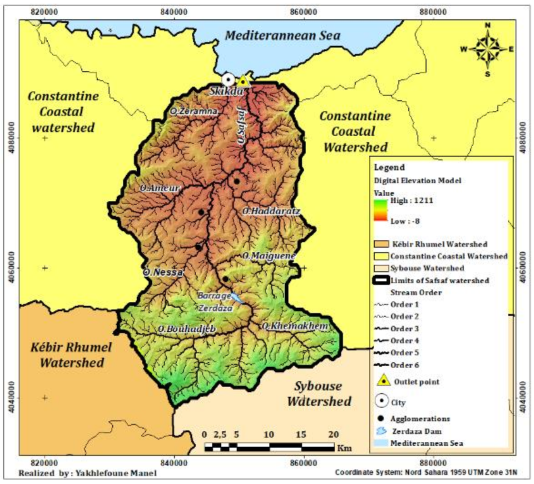


**Fig. 7: Situation of the Safsaf watershed**

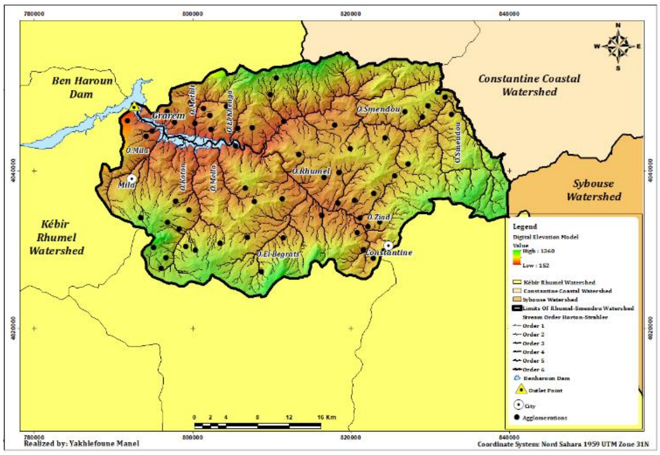


**Fig. 8: Situation of the Rhumel Smendou watershed**

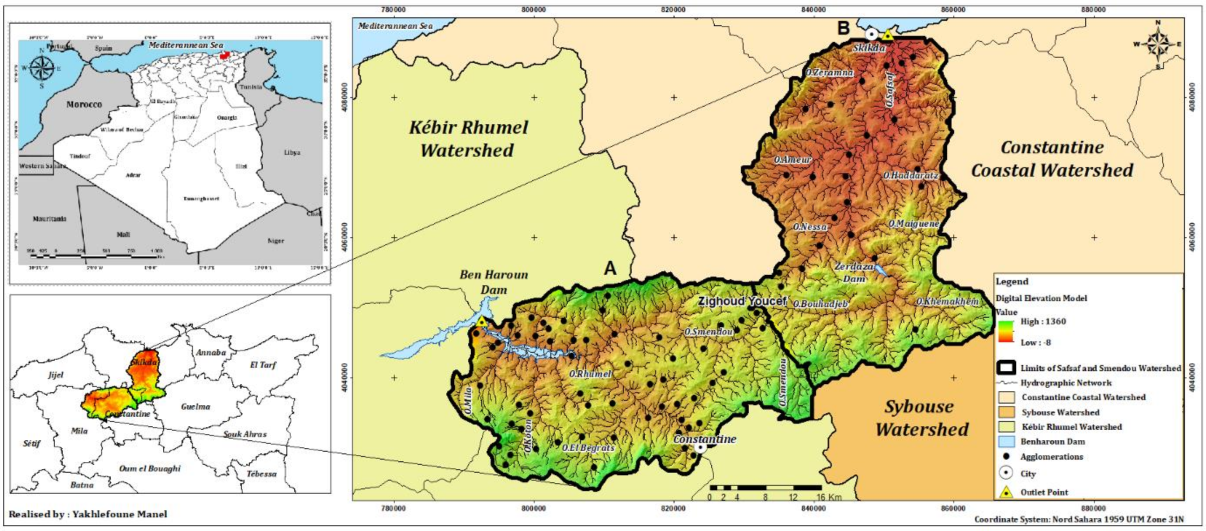


**Fig. 9: Localisation of the Rhumel-Smendou and Safsaf watershed and regressive erosion, A - Rhumel Smendou watershed, B - Safsaf watershed**

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## Methodology of producing the fluvial geomorphology map in the North-East of Algeria – identification of vulnerability factors

The elaboration of the fluvial-geomorphology map of the North East of Algeria was carried out based on:

- The map of the hydro-climatological network made by the national agency of hydraulic resources (ANRH) on a scale of 1/500000 (2006 edition).

- The "Shutter Radar Topography Mission" SRTM was used to delineate a digital elevation model (DEM) with a resolution of 30 meters.

In order to process this digital elevation model, ArcGIS 10.8 software was used to generate the watershed, sub-watershed and hydrography network of the North-East of Algeria which are the Constantine coastal watershed (Fig. 7, 8, 10), the Kebir Rhumel watershed, and the Sybouse watershed, the studied area is divided into three Zones:

- The first zone is the Constantine coastal zone located on the northern slope of the Numidic chain (Fig. 7, 10).

- The second zone is the intramountain zone (Fig. 9, 10); situated between the coastal and the north slope of Numidic chain zone.

- The third zone is the interior zone limited between the south slope of Numidic chain from the north and Constantine mountains to the south (Fig. 8, 10).

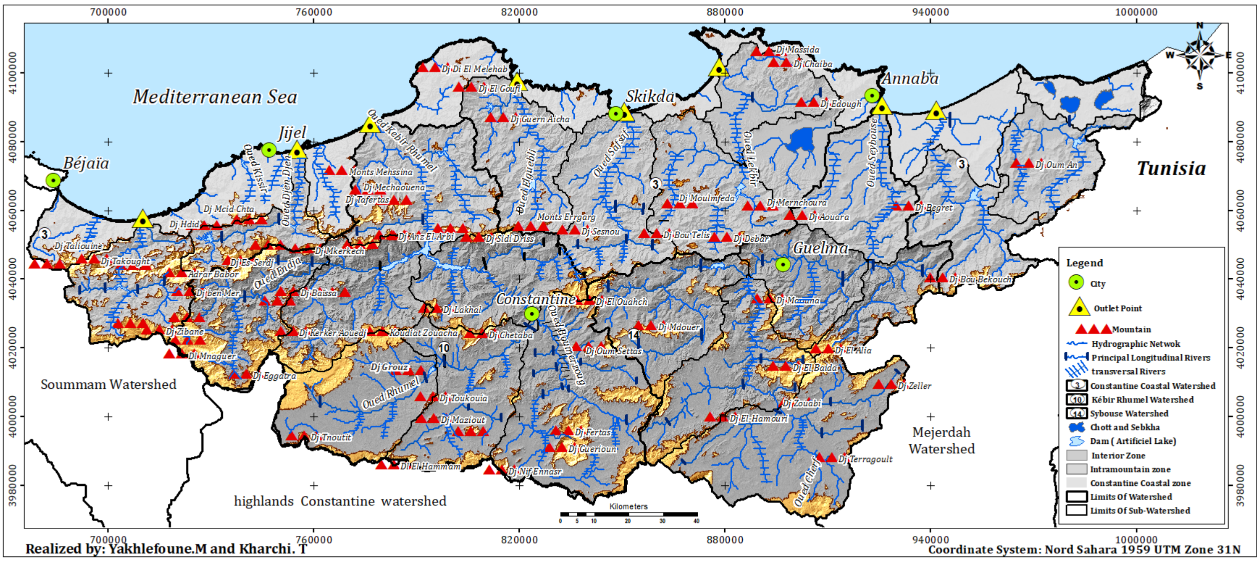



**Fig. 10: The fluvial geomorphology map of the North East of Algeria**

This important map shows the genesis and the evolution of the hydrographic network of the Maghribides chain (North-East of Algeria). There is a concordance between the mountains and the hydrographic network, the rivers in longitudinal with the mountains (Numidic chain) take the East-West direction. Moreover, the transversal rivers have a South-North direction.

It is necessary to take into consideration the heritage and the geological history during the evolution of the relief. The active dynamic of northern Algeria and the eastern part in particular, favours the genesis and the evolution of instabilities, which are mostly caused by terrain deformations. A complex morpho-structural context frequently promotes and guides these deformations (Benabbas, 2006, Benzid, 2017; Benabbas et al., 2018).

The watersheds of the North-East of Algeria form a Mediterranean region with a large variety of erosional processes. The Pliocene topography formed the basis for the evolution of the hydrographic network of the North-East of Algerian Watersheds. After that, tectonic activities gave the region its mountainous appearance (Maghribides chain) which develops progressively at the end of the Pliocene. These active tectonic movements are also responsible for the resumption of river down cutting, which may incise deep valleys and gorges. (Khanchoul and Saaidia, 2017).

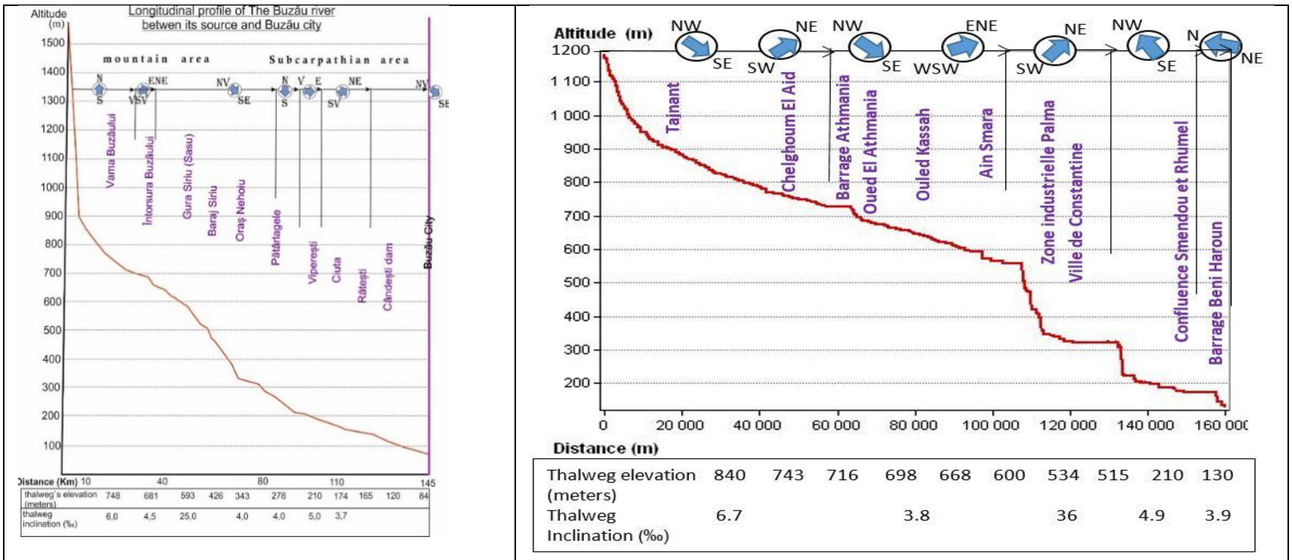
A B

**Fig. 11: A - Coastal zone in Collo; B - Intramountain zone**

### The role of the slope in the dynamics of the river

Energy component of water masses (dependence on velocity, gravity, depth of current and absolute absence) (kinetic energy is equal to 1/2 (mv2).

1. Various longitudinal profile on the slope depending on the relief shape (Fig. 12 A, B);
2. River level;
3. River processes - erosion and accumulation (Fig. 4);
4. Analysis of deposits - reliefs (reeds, islets) and Granulometry (sampling, laboratory analysis);
5. The islets of the Buzău River in the Întorsura valley.




A B

**Fig. 12: A - Longitudinal profile: Buzău; B - Longitudinal profile: Rhumel**

### Tectonic risk within the Curvature Carpathians

The Buzău River basin is located in a region known for its tectonic mobility specific to the Curvature Carpathians (Visarion et al., 1977). This tectonic mobility is maintained by the frequency of earthquakes in the Vrancea seismic region, with earthquakes of more than 7 degrees Richter. Each earthquake is a risk factor for the triggering of geomorphological processes of the watershed and the riverbed.

The mountainous and Sub-Carpathian region is part of the sedimentary flysch of the Cretaceous, Paleogene, Mio-Pliocene and plain unit. The Quaternary with fluvio-lacustrine deposits, is dominated by

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rocks less resistant to erosion, which favours the supply of sediments in the subsurface areas (Săndulescu et al., 1968; Grecu et al., 2007).

The elevation and the subsidence movements require reorganization of the hydrographic network through captures, at the alternation of the erosion and accumulation processes and thus at the creation of a certain river style (Sembroni et al. 2021). In the Curvature Carpathians, the formation of the Buzău River shows a stage of formation, with varying intensities, due to the subsidence areas from Întorsura Buzăului and from the Romanian Plain. In the Întorsura Buzăului area there are intense processes of accumulation in oysters on the background of a longitudinal profile with extremely low slope. This is an area where there is frequent flooding. In the Romanian Plain, the meandering processes (lateral erosion, accumulation) are accompanied by floods and excess humidity.

In the mountain area, the elevation movements are 3-5 mm/year, with some slight local subsidence (ex: Întorsura Buzăului). In the plain towards the confluence area reach 7-8 mm/year. The slope accentuated in the upper watercourse and the slope reduction favoured river depletion and accumulations, forming oyster. In these conditions, torrential rainfall floods occur.

## The tectonic risk in the Zighoud Youcef region (NE of Constantine)

The rivers in the North-East of Algeria, in the Zighoud Youcef area, form a hydrographic knot composed of waters between the Rhumel-Smendou and SafSaf watershed (Fig. 9). Morphometric and hydrogeomorphological analysis reveals a total transverse river/Rhumel Smendou watershed and a river entered into Zighoud Youcef depression probably by capture. This particular morphology was probably guided and accelerated by a morpho-structural context represented by the active tectonic activity that the region has experienced during the end of the Pliocene and during the whole Quaternary (Benabbas et al., 2019; Benabbas et al., 2021). So, the remnants of the hydrographic network are also influenced here by tectonics and lithology.

The watersheds have the same order of size (6) (after Horton 1945, Strahler 1952, Zăvoianu 1985, Grecu 2004) and similarities in the source area. In the field there is a more active regressive erosion of the tributaries of the Rhumel-Smendou watershed, probably influenced by the level of the accumulation lake and lithology (Fig. 7, 8).

Within the Zighoud Youcef area, the watershed between the neighbouring basins (Oued Sbikra and Ben-Brahim Bouhadjeb) is subjected to regressive erosion processes, landslides specific to an imminent catch (Fig. 13). This fact is also proved by the large number of 1st and 2nd order river segments with regressive character. Their average length from less than 0.50 km to 1.00 km attests to the high degree of torrentiality (Fig. 13).

The achievement index below 50% for the number of segments and for the lengths shows an imbalance in the basin of the order 6 size.

**A** **B** **C**

**Fig. 13: A - Regressive erosion of the Beni Brahim-Bouhadjeb river; B – settlement and road on water scale; C - Upstream part of the Oued Beni Brahim-Bou Hadjeb river**

The morphometric analysis of the drainage network with the Horton-Strahler classification allows comparisons in the genesis and dynamics of river segments and the vulnerability of the land to hydro-geomorphological processes. In this context, the morphometry of some rivers in contact sub-basins of tectonic significance was made as follows (Fig. 10, 13, 14):

1. Rivers with springs susceptible to imminent capture (RL longitudinal rivers) and responsible for modifications of the common (frontal) water table in the

Zighoud Youcef area of the Rhumel-Smendou watershed, Oued Sbikha and SafSaf – Oued Beni Brahim-Bouhadjeb basins;

2. Rivers (SafSaf and Sbikha) in basins developed on the north-Mediterranean slope, (see fig. map of fluvial geomorphology) transverse rivers (RT), with active regressive erosion towards the watershed with the basins of longitudinal rivers (RL).

Morphometric analysis shows remarkable similarities in the dynamics of the RL rivers by bifurcation ratio (3.79 and 3.54 respectively) and the degree of realization. We specify that morphometric analysis on the whole catchment of ordinal 6 (Rhumel-Smendou and SafSaf watershed) shows the same situation. In both basins, the number of order 1 and 2 organisms is about 1100, and the confluence ratio per RC basin is 4.18 and 4.28 respectively.

The maps of landslides at the top of the gullies show their elongation by complex slope processes, favoured by the specific geological substrate of the Mio-Pliocene flats. There is however a dominance of these processes in the whole region (Manchar et al., 2019). In conclusion, the analysis of the lower segments signals an increased vulnerability in the area of the water ridges. However, it cannot support an imminent catchment under similar river conditions, with current dynamics dictated by the local base level (dam, lake). Relevant data for this purpose could be revealed by the analysis of river lengths over the entire catchment, but for paleo evolutionary situations.

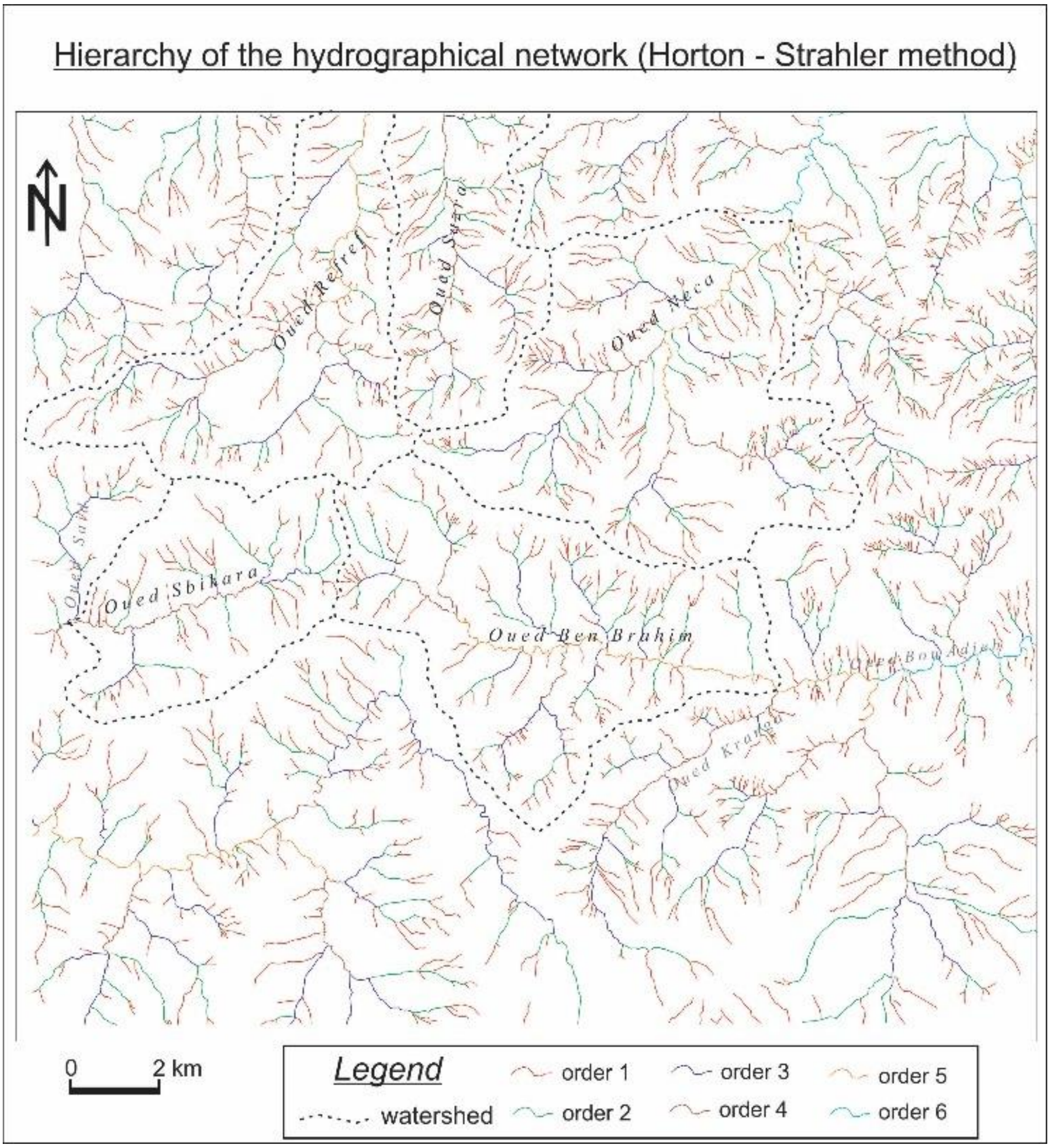


**Fig. 14: Rhumel-Smendou and Safsaf sub-watershed, Horton Strahler hierarchy and torrential erosion in the Ziroud Youcef area**

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## Conclusions

The Întorsura Buzăului sector and the Constantine area are distinguished by an active tectonic, the active dynamics of the river bed and also by hydrotechnical works against floods, regularization of the minor river bed, shore defence. In the tendency to rebalance the riverbed, the response of the analysed rivers is different in longitudinal profile and in transversal profile.

The Buzău River forms a sinuous and unique pattern in the Carpathians, a braiding one in the Sub-Carpathian and piedmont plain, and a meandering one in the lowlands. This is a general picture, because the limits between these patterns are not precise and there are also intermediary types (Grecu, 2018). The braiding pattern corresponds to a slope of 2.7 m/km and it covers 88 km in length (Grecu et al., 2014, 2017 b).

The important variations of the active channel's width at the entrance in the piedmont plain in the vicinity of confluences, which indicate the role of tributaries in bringing yield in the main channel (Toroimac et al., 2010; Dumitru, 2020). The average width diminished by 69% in 25 years (1980-2005) (Grecu et al., 2014). The braiding channel could be easily reactivated during extreme floods (Negru, 2010).

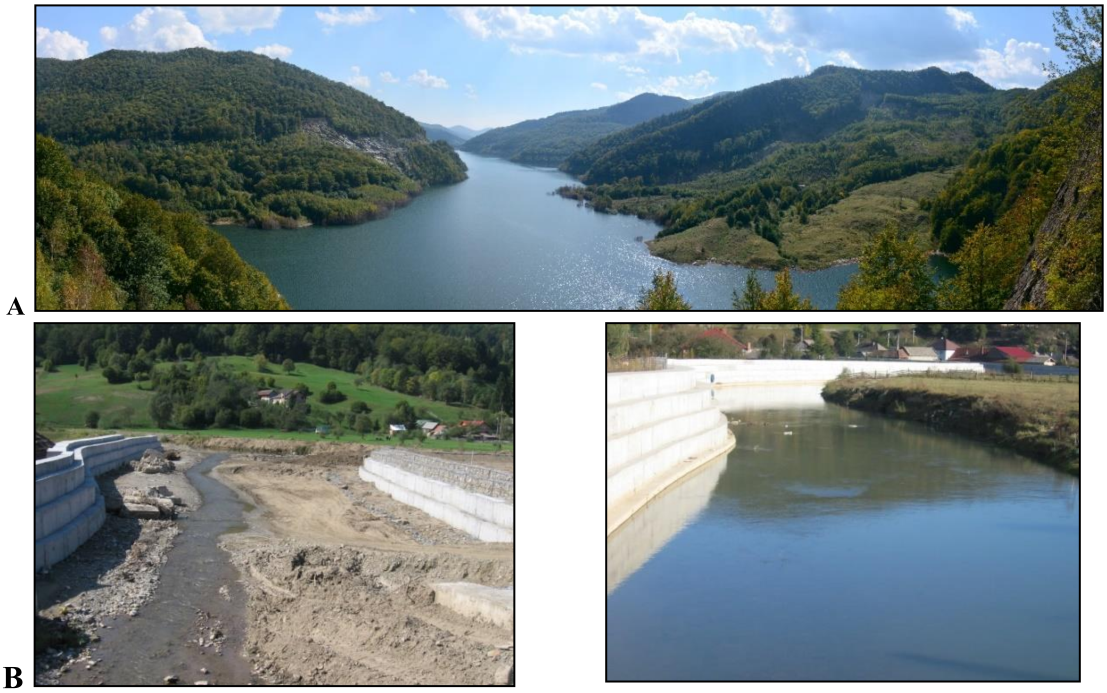

**Fig. 15: Anthropic arrangements of the Buzau River: A - Siriu Accumulation Lake, basic local level with influence in the current dynamics of the slopes: erosion and massive landslides (photo Mircea Vișan 2017). B - River arrangement works against floods in the Întorsura Buzăului Depression (protective wall and gabions)**

**Fig. 16: Anthropic arrangements: the Rhumel River in Constantine area (Kebir-Rhumel Watershed)**

A B C

**Fig. 17: A - The Rhumel River in the central Constantine gorge; B - at the exit of the pier; C - slopes affected by erosion and landslides in the peri-urban area of Constantine**

A B

**Fig. 18: A - Landscaping in Constantine; B - suspension bridge over the Rhumel gorge in the city**

In the Numidic chain, there is a direct reporting of the drainage network to the mountain peaks and depression areas, compared to which they are transversal, respectively longitudinal (see geomorphological map). The current dynamics of the riverbed in the Rhumel basin, for example, is anthropically influenced by the creation of local base levels. In the current state of our research, we cannot assess their antecedent, epigenetic character or the role of catchments, some riverbeds being probably petrographic. However, the role played by regressive erosion in the tendency of frontal catchments and of the widening of some hydrographic basins to the detriment of the adjacent ones is evident. The basic levels created by the accumulation lakes have a major importance in the current dynamics of the rivers by the modification brought in the longitudinal profile, by the acceleration of the erosion on the slope and in the riverbeds. Excavation of gravels, by artificial elevation of meadows (observations and field research in the Constantine area towards Annaba, Skikda, Collo, Jijel, Guelma, etc.)

The risk of floods-imposed regularization of the riverbed, with methods specific to each segment of the mountain, hilly or plain (Buzău River and Rhumel River) (Fig. 4, 15, 16, 17).

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