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Estimation of the Quaternary stream erosion in small drainage basins (Vâlcea sub-Carpathians and Olteţ Plateau, Romania)

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Abstract

Stream erosion is a widely spread process in the Getic sub-Carpathians and Plateau (including the study sub-units). It is controlled by the high density of small drainage basins on a surface unit. Development of the 4th and 5th order valleys (according to Strahler's system) in the sub-Carpathians and of the 3rd and 4th order in the Olteţ Plateau was also determined by the high altitude of hillslopes, up to 450 meters in the Vâlcea sub-Carpathians and to 250 meters in the Olteţ Plateau, a consequence of the strong downcutting performed by the Olt river and its main tributaries in this area (Olăneşti, Bistriţa, Cerna and Olteţ). Another control factor is the friable bedrock made of sedimentary deposits: conglomerate, gravel, sand, sandstone, marl, clay, tuffs etc. in the Vâlcea sub-Carpathians and Cândeşti strata (gravels with clayey lens of Villafranchian age) in the Olteţ Plateau.

Keywords: *Small drainage basin, Stream erosion, Geomorphic balance, Sub-Carpathians, Getic Plateau*

Rezumat. Estimarea eroziunii din timpul Cuaternarului în bazinele hidrografice mici (Subcarpații Vâlcei și Podișul Oltețului, România)

Eroziunea torențială este un process cu largă răspândire în Subcarpații și Podișul Getic, inclusiv în subunitățile în care s-a efectuat studiul. Amploarea acestui proces hidro-geomorfologic este pusă în evidență de densitatea mare a organismelor torențiale raportate la unitatea de suprafață. Dezvoltarea bazinelor torențiale de ordinele IV și V (conform sistemului de ierarhizare Strahler) în Subcarpați și de ordinele III și IV în Podișul Oltețului a fost favorizată și de amplitudinea mare a versanților, de până la 450 m în Subcarpații Vâlcei și de până la 250 m în Podișul Oltețului, determinată de adâncirea accentuată a râului Olt și a principalilor afluenți din acest areal (Olănești, Bistrița, Cerna și Olteț). La aceasta se adaugă friabilitatea substratului geologic, format din depozite sedimentare: conglomerate, pietrișuri, nisipuri, gresii, marne, argile, tufuri ș.a. în Subcarpații Vâlcei și strate de Cândești (pietrișuri cu lentile argiloase de vârstă villafranchiană) în Podișul Oltețului.

Cuvinte-cheie: *Bazin hidrografic mic, Eroziune torențială, Bilanț geomorfologic, Subcarpați, Podișul Getic*

Introduction

Physical geographers and geomorphologists have constantly approached the problematic of drainage basin processes within their studies (Roehl, 1962; Gregory & Walling, 1973). Since the first significant theoretical debate conducted by Walling, (1983) regarding the sediment erosion and delivery, some researchers have paid special attention to the problem of the amount of eroded material within drainage basins (Lu et al., 2004; Lu et al., 2005). Most of the recent studies approached the GIS environment implementation. Walling's theory has been recently revised, with authors focusing on area-specific sediment yield or SSY (de Vente et al., 2007). Other papers concerned on dividing basin areas into smaller, morphological units to facilitate quantitative analyses on the sediment delivery ratio and increase the accuracy of results (Ferro & Minacapilli, 1995). The Italian geographic school had similar concerns over this subject (Pellegrini, 1983; Lupia Palmieri et al., 1998; Vianello et al., 2004; Zaccagnini, 2005), and more recent papers even developed a GIS-based approach (Vivenzio, 2002). A special attention on sediment delivery over the Romanian territory was paid by Rădoane & Rădoane (2005). Most of the Romanian studies regarding this matter focused on evaluating the gully erosion within gullying-affected landforms, particularly Moldova and Getic Plateaus (Bălteanu & Taloescu, 1978; Rădoane et al., 1999; Boengiu, 2008). Previous research on evaluating the volume of removed sediment was conducted on different landforms in Romania: Banat Mountains (Popescu, 1989); Getic Piedmont (Popescu, 1986; Ene et al., 2010; Boengiu et al., 2012); Argeș (Ene & Nedelea, 2007), Vâlcea (Ene, 2001; Tîrlă, 2012) and Curvature sub-Carpathians (Popescu et al., 2003).

Small drainage basins – reference geomorphological units in stream erosion analyses

While gullies are simple physical products of linear erosion, drainage basins result from complex branching stream erosion, which is hierarchically superior. The two main features of a small drainage basin are: a relatively low order of the collector stream, and having ”similar physiographic conditions over the whole of its surface” (Toth, 1963). Classification of drainage basins into large, medium and small (having multiple sub-units) is generally based on area size and stream order, as these two criteria were widely accepted as being the most relevant in empirical geomorphological studies (Rădoane, 2002). Under the circumstances, the basins analyzed in this paper are classified as ‘small’ since they have areas under the threshold value of 100 km^2 and 3rd or 4th stream order using Strahler’s classification system (Strahler, 1957). They shall be further referred to either as small basins, sub-basins or catchments.

This study aims to contribute at developing the previously initiated research in the sub-Carpathian and plateau areas in Romania and quantitatively estimate the rate of erosion in small drainage basins during the Quaternary. In order to achieve this goal, we calculated the volume of eroded and evacuated sediment, concomitantly with the stream network development, and finally show the geomorphic balance of the analyzed landforms.

Morphogenetic conditions

A total of 27 small drainage basins were subject to analysis: 7 basins in the Vâlcea Sub-Carpathians and 20 basins in the Olteţ Plateau (Fig. 1, Table 1). The Sub-Carpathian sub-basins are tributary to the Olt, Olănești and Govora rivers, whereas the plateau sub-basins are tributary of the Cerna, Cernișoara and Luncavăț.

The geomorphic evolution of the Vâlcea sub-Carpathians and Olteţ Plateau was and still is controlled by a series of conditional factors (geology, structure, neotectonic movements, vegetation etc.) and triggering factors (precipitation regime, underground water circuit etc.). The type of bedrock and neotectonic movements control the intensity of erosion. We distinguished three major geological layers in the analyzed catchments (Fig. 1):

- A relatively resistant Miocene layer consisting of conglomerate, gravel, tuffs, schist and marl, found within the bedrock of 5 catchments (Glâmboaca, Pleşii, Buneşti, Strâmba and Tulburoasa), located in the north-central Vâlcea sub-Carpathians;
- A friable Upper Miocene layer (Sarmatian deposits: sand, sandstone, marl, clay, clay with coal intercalations, etc.), found only in the Creştetului and Vlădeşti catchments, located in the south-central Vâlcea sub-Carpathians;
- A Villafranchian layer consisting of gravel deposits with sand and clay intercalations (Cândeşti strata), partly mantled by loess deposits and found within all the catchments in the Olteţ Plateau.

The intensity of neotectonic movements register positive values, ranging from 0.7 mm/year in the Olteţ Plateau to 2.5 mm/year in the north-central Vâlcea sub-Carpathians (Visarion et al., 1977; Zugrăvescu et al., 1998). Precipitation is variable in this area, with heavy rainfall on summer (over 50 l/m2/day sometimes). During the last 2,000 years (and more aggressively during the last 200 years), another factor – humans – has interfered by deforesting large areas.

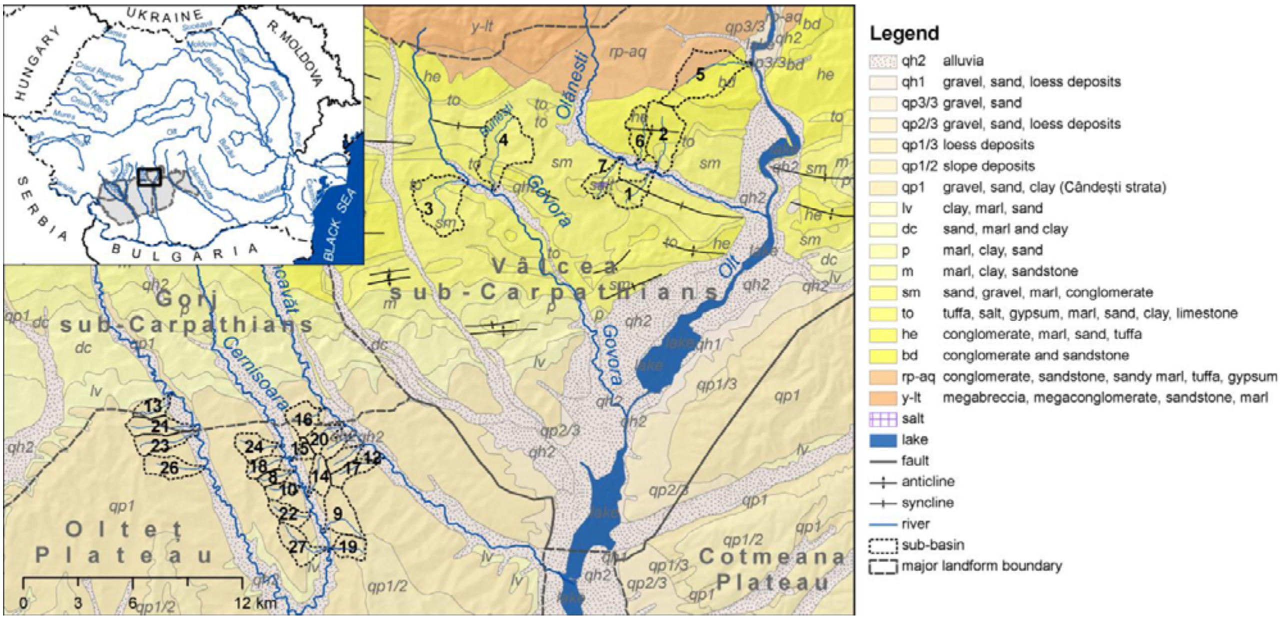

Fig. 1: Geographical setting and geology of the study sub-basins. Numbers correspond to sub-basin names given in Table 1, and the location of study area (in black) within the major landform units (in gray) is indicated in the vignette. Geology processing after (Codarcea, et al., 1967; Bombiță, et al., 1967)(SRTM, 2000; DEM by authors)

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Research methodology

We have chosen a method of determining the total fluvial erosion by calculating the evacuated volume of the studied sub-basins. Starting from the idea that the volume of the negative shape of a sub-basin is approximately equal to the volume of the material removed by erosion since that basin started to form, one can estimate the volume of material eroded during the entire evolution of that basin (Popescu, 1986). A model illustrating how the basins are divided into square units and the types of numerical analyses performed, is shown in Figure 2.

All input data were obtained by calculations according to formulas below. Topographic maps of scale at 1:25,000; geological maps of scale at 1:200,000 (Codarcea, et al., 1967; Bombiță, et al., 1967); and the neotectonic map of Romania of scale at 1:4,000,000 (Zugrăvescu et al., 1998) form the cartographic basis used within the study.

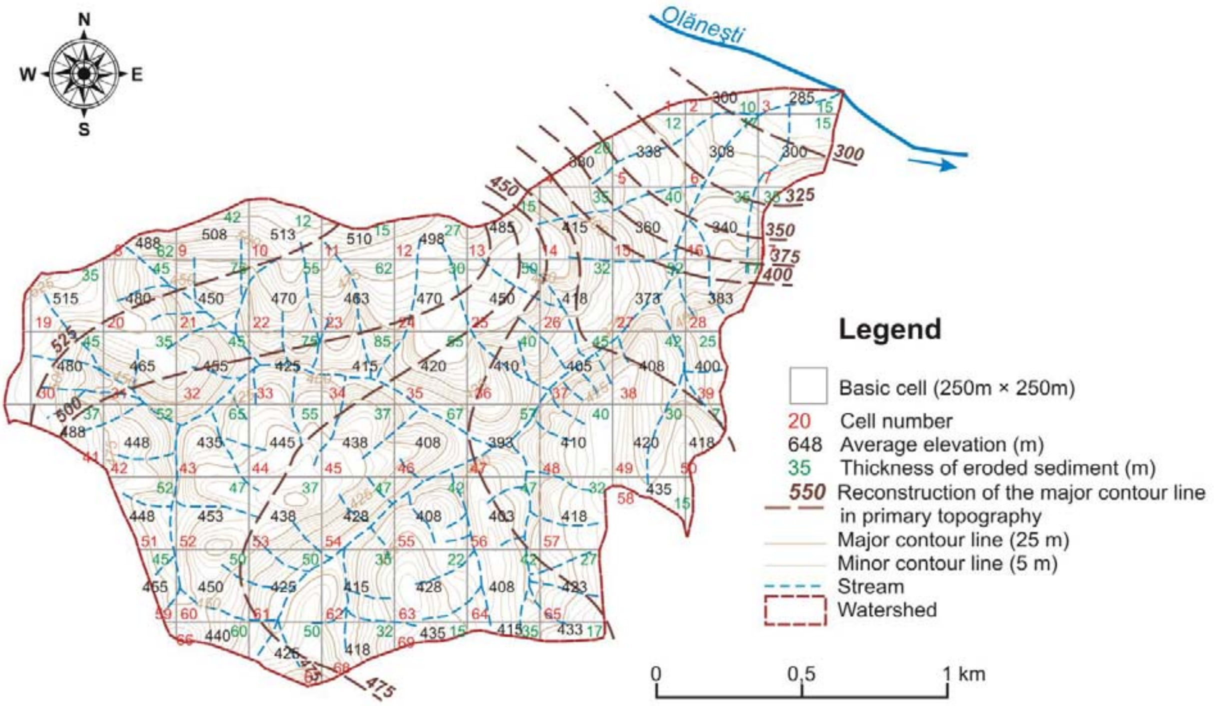

Fig. 2: Graphical and numerical analysis model applied to Glâmboaca sub-Carpathian catchment

Main working stages:

Select a series of small catchments of the same order if possible;

Measure the area for each catchment (S_b) – Fig. 3, Table 1;

Split the basin areas into cells of 250 x 250 m (62,500 m^2) which are the basis for calculation;

Calculate the average elevation (H_{med}) of each surface unit;

$$H_{med} = \frac{Alt_{max} + Alt_{min}}{2}$$

Reconstitute the primary surface as the evolution base for the gullies; in order to obtain more accurate results, we correlated all the "pieces" left from the primary level, and corrections were applied by tracing several cross sections over each catchment (Fig. 4);

Calculate the thickness of the eroded material for each surface unit:

$G_{er} = H_i - H_{med}$ (m),

where H_i is the primary average elevation.

Calculate the volume of eroded material (V_{er}) on the surface unit and the total volume of eroded material (Vt_{er}) for each analyzed catchment:

$V_{er} = G_{er} \times S$ (m_3)

$Vt_{er} = \sum V_{er}$

Calculate the eroded specific volume for each analyzed catchment (Vs_{er}):

$$Vs_{er} = \frac{Vt_{er}}{S_b} \ (m_3/km^2)$$

Calculate the specific erosion (rate of erosion, Er_s):

$$Er_s = \frac{Vs_{er}}{T} \ (\frac{m^3}{km^2}/year),$$

where T is the time during which the analyzed catchments formed.

To estimate the time necessary for the analyzed catchments to form, we considered that the moment since the erosion processes and evacuation of materials started can be placed at the end of Mindel glacial phase for the sub-Carpathian basins and at the end of the Würm I glacial phase for the 2nd generation catchments in the plateau area (Popescu, 1986; Badea & Dinu, 1987).

Results

The basin areas vary from 1.08 km^2 in Valea Şibiţei to 12.2 km^2 in Valea Şasa (Fig. 3). After calculating the total volume removed, there resulted that in most of these cases its value is directly proportional to the catchment's area. The average of eroded specific volume is 48.7 × 10^6 m^3/km^2 for the catchments in the Vâlcea sub-Carpathians and 47.78 × 10^6 m^3/km^2 for the catchments in the Olteţ Plateau (Fig. 4). This demonstrates that similar climatic and geological conditions controlled their evolution (including the highly friable bedrock, even if the facieses differ within the two landforms). The slightly higher hardness of rocks in the Vâlcea sub-Carpathians was counterbalanced by the more intense uplift of the area, resulting in a higher rate of hillslope erosion.

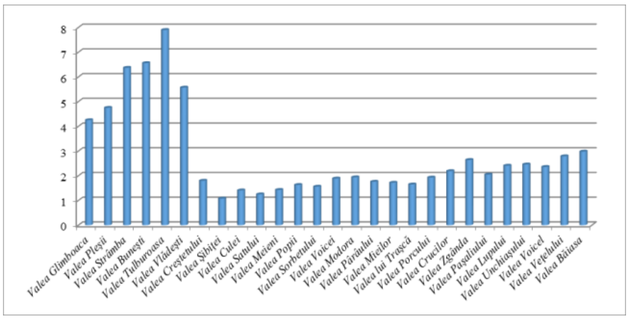

Fig. 3: The area of the catchments (in km2)

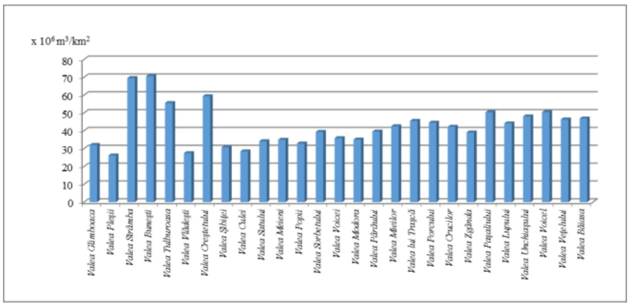

Fig. 4: Eroded specific volume (x 106 m3/km2)

Table 1: Basin area (Sb), total eroded volume (Vter) and specific eroded volume (Vser)

No.	Catchment	S_b (km^2)	Vt_{er} (x 10^{6}m^3)	Vser (x 10^{6}m^3/km^2)	Collector river	Landform unit
1	Valea Glâmboaca	4.25	86.2	32.1	Olănești	Vâlcea sub-Carpathians
2	Valea Pleşii	4.75	124.2	26.2	Olănești	
3	Valea Strâmba	6.37	443.5	69.6	Govora	
4	Valea Buneşti	6.56	463.4	70.7	Govora	
5	Valea Tulburoasa	7.90	438.9	55.6	Olt	
6	Valea Vlădeşti	5.57	153.2	27.5	Olănești	
7	Valea Creştetului	1.80	106.9	59.4	Olănești	
8	Valea Şibiţei	1.08	33.3	30.83	Cernișoara	Olteţ Plateau
9	Valea Culei	1.41	40.2	28.51	Cernișoara	
10	Valea Satului	1.25	42.8	34.24	Cernișoara	
11	Valea Meieni	1.43	50.1	35.03	Luncavăț	
12	Valea Popii	1.63	53.6	32.90	Luncavăț	
13	Valea Sorbetului	1.56	61.4	39.36	Cerna	
14	Valea Voicei	1.89	67.8	35.87	Cernișoara	
15	Valea Modoia	1.94	68.1	35.10	Cernișoara	
16	Valea Pârâului	1.76	69.6	39.55	Luncavăț	
17	Valea Meilor	1.72	73.3	42.62	Luncavăț	
18	Valea lui Traşcă	1.65	75.3	45.64	Cernișoara	
19	Valea Porcului	1.93	86.0	44.56	Cernișoara	
20	Valea Crucilor	2.19	92.6	42.28	Luncavăț	
21	Valea Zgânda	2.64	103.3	39.13	Cerna	
22	Valea Paşaliului	2.05	103.4	50.44	Cernișoara	
23	Valea Lupului	2.41	106.5	44.19	Cerna	
24	Valea Unchiaşului	2.46	118.4	48.13	Cernișoara	
25	Valea Voicel	2.36	119.2	50.51	Cernișoara	
26	Valea Veţelului	2.79	129.5	46.42	Cerna	
27	Valea Băiașa	2.98	139.9	46.95	Cernișoara	

In order to determine the specific erosion (Ers) and the rate of erosion (D), the eroded specific volume has been related to the time necessary for each analyzed catchment to form and develop (Popescu, 1986). The geomorphic balance was calculated on the basis of knowing the rate of erosion (D) and the value of neotectonic uplifts (Fig. 5, Table 2), using data from neotectonic maps of the Romanian territory (Cornea et al., 1979; Visarion et al., 1977; Zugrăvescu et al., 1998).

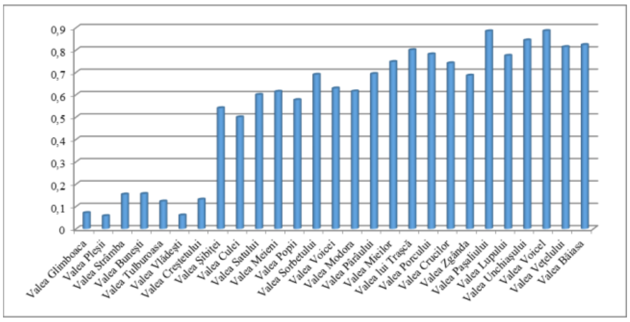

Fig. 5: Rate of erosion (mm/year)

Table 2: Specific erosion (Ers), rate of erosion (D), value of neotectonic uplift (M) and geomorphic balance (B)

No.	Catchment	T (years)	Ers (m³/km²/year)	D (mm/year)	M (mm/year)	B (mm/year)
1	Valea Glâmboaca	450,000	71.8	0.0718	+1.5	+1.43
2	Valea Pleşii	450,000	58.2	0.0582	+1.5	+1.44
3	Valea Strâmba	450,000	154.7	0.1547	+1.8	+1.65
4	Valea Buneşti	450,000	157.1	0.1571	+1.8	+1.64
5	Valea Tulburoasa	450,000	123.5	0.1235	+2.5	+2.37
6	Valea Vlădeşti	450,000	61.1	0.0611	+2.5	+2.44
7	Valea Creştetului	450,000	132.0	0.1320	+1.8	+1.67
8	Valea Şibiţei	57,000	540.9	0.5409	+ 0.7	+0.16
9	Valea Culei	57,000	500.2	0.5002	+ 0.7	+0.20
10	Valea Satului	57,000	600.7	0.6007	+ 0.7	+0.10
11	Valea Meieni	57,000	614.6	0.6146	+ 1.0	+0.39
12	Valea Popii	57,000	577.2	0.5772	+ 1.0	+0.42
13	Valea Sorbetului	57,000	690.5	0.6905	+ 0.7	+0.01
14	Valea Voicei	57,000	629.3	0.6293	+ 0.7	+0.07
15	Valea Modora	57,000	615.8	0.6158	+ 0.7	+0.15
16	Valea Pârâului	57,000	693.9	0.6939	+ 1.0	+0.31
17	Valea Mieilor	57,000	747.7	0.7477	+ 1.0	+0.25
18	Valea lui Traşcă	57,000	800.7	0.8007	+ 0.7	-0.10
19	Valea Porcului	57,000	781.8	0.7818	+ 0.7	-0.08
20	Valea Crucilor	57,000	741.8	0.7418	+ 1.0	+0.26
21	Valea Zgânda	57,000	686.5	0.6865	+ 0.7	+0.01
22	Valea Paşaliului	57,000	884.9	0.8849	+ 0.7	-0.18
23	Valea Lupului	57,000	775.3	0.7753	+ 0.7	-0.08
24	Valea Unchiaşului	57,000	844.4	0.8444	+ 0.7	-0.14
25	Valea Voicel	57,000	886.1	0.8861	+ 0.7	-0.19
26	Valea Veţelului	57,000	814.4	0.8144	+ 0.7	-0.11
27	Valea Băiașa	57,000	823.7	0.8237	+ 0.7	-0.12

After the evaluation process one could notice that most of the analyzed catchments have a positive geomorphic balance, especially in the sub-Carpathians. Values range from +1.43 mm/year (V. Glâmboaca) to +2.44 mm/year (V. Vlădeşti), which demonstrates that the landform uplifts quite rapidly, due to its proximity to the mountain area, which exceeds +3 mm/year in uplift. Consequently, external modeling agents do not succeed in eroding and removing the sediment as fast as the uplifts.

The catchments in the Olteţ Plateau register different values of geomorphic balance, from +0.42 mm/year (V. Popii) to -0.19 mm/year (V. Voicel), much lower than those in the Vâlcea sub-Carpathians. There are several factors responsible for this situation, such as the lower rate of neotectonic uplift (between +0.7 mm/year and +1.0 mm/year) and the higher friable bedrock. These conditions impose a rate of erosion up to ten times higher for the catchments in the Olteţ Plateau (Fig.

5) comparing to those in the Vâlcea sub-Carpathians. The Voicel catchment reaches the maximum value (0.8861 mm/year).

A number of 8 catchments have a negative geomorphic balance (Fig. 6). They are located in a lowly uplifting area (+0.7 to +1.0 mm/year). Overall, the Olteţ Plateau has a positive geomorphic balance, but the lower values (an average of 0.08 mm/year) comparing to Vâlcea sub-Carpathians (average of 1.81 mm/year) demonstrate a strong degradation by geomorphic processes, hardly counterbalanced by the neotectonic uplifts.

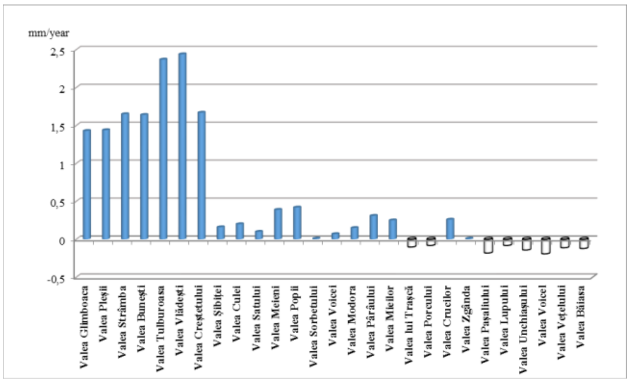

Fig. 6: Geomorphic balance (mm/year): blue = positive; white = negative

Table 3: The current rate of erosion (D) for catchments in the Vâlcea sub-Carpathians and Olteţ Plateau

Major drainage basin	Landform	D (mm/year)
Olăneşti	Vâlcea sub-Carpathians	0.393
Bistriţa	Vâlcea sub-Carpathians	0.258
Olteţ	Olteţ Plateau	0.540

Discussions

The current topography is a remnant of what at the end of Pliocene used to be a homogenous surface area, subject to stream downcutting during the Quaternary.

By comparing the results obtained to the present average values of the rate of erosion (Popescu, 1986) for the catchments in the Vâlcea sub-Carpathians and Olteţ Plateau (Table 3), we can notice that currently the erosion is more intense in the Vâlcea sub-Carpathians, possibly due to a much stronger anthropogenic activity, especially during the last 200 years. The particularly strong erosion in the Glâmboaca basin, followed by a massive sediment delivery was triggered by the uplift of salt in the nearby Sărata basin to the south. Reconstruction of the primary topography in the Olănești basin seems to certify the previous existence of a pre-Quaternary (Pliocene) erosion surface. In the Olteţ Plateau the phenomenon reverses – the rate of erosion is low if comparing to the values obtained for the whole time necessary for the catchments to form and develop. It can be explained if considering the very intense erosion during the Würm II glacial phase and the late-glacial period, when vegetation was lacking on large areas or it was very sparse.

Conclusion

Estimation of stream erosion (the main process controlling the evolution of hillslopes and landforms) by calculating the total volume of eroded material could be a useful geomorphic analysis method; the values obtained demonstrate the rhythm of erosion within various types of valleys.

Assessing the age of the primary topography in sub-basin areas is useful for a more accurate estimation of the geomorphic balance.

The values of specific erosion calculated for the sub-basins in which the solid discharge is not directly measured could be used as key-indicators in land reclamation works.

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River Change Detection and Bankline Erosion Recognition using Remote Sensing and GIS

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Abstract

Bangladesh is mainly formed by alluvial deposits, facing riverbank erosion very frequently due to unvarying alteration of river channels. This study is aimed at computing the actual bank shifting along the Manu River within Bangladesh for a period of thirteen years (1997-2010). The entire course of Manu River from upstream of India Border, Moulvibazar to the confluence with the Kushiyara River at Manumukh, Sherpur for a stretch of around 69 km has been studied using an integrated approach of Remote Sensing and Geographical Information System (GIS). The channel configuration of the Manu River has been mapped for the years 1997 and 2010 using Landsat satellite images. The analysis divulged that the Manu River is a highly meandering river with several very critical sections where the river has been suffering enormously with the erosion problem and shifting characteristics. The enumerated river shifting was found very high as the maximum left bank shifting and maximum right bank shifting had occurred at Rajnagar, Moulvibazar of 656 m and 628 m respectively, in the mentioned period. The results deliver latest and steadfast evidence on the dynamic fluvio-geomorphology of the Manu River for designing and execution of erosion control schemes.

Keywords: *River morphology, Bankline migration, Remote sensing, GIS*

Rezumat. Detectarea schimbărilor cursului râului și recunoșterea sectoarelor cu eroziune a malurilor folosind teledetecția și SIG

Bangladesh este format în principal din depozite aluviale, eroziunea fluvială fiind foarte frecventă datorită modificării continue a alviilor râurilor. Acest studiu își propune să evalueze modificările actuale ale malurilor râului Manu în Bangladesh pentru o perioadă de 13 ani (1997-2010). Întregul curs al râului Manu, de la granița cu India, Moulvibazar, până la confluența cu râul Kushiyara la Manumukh, Sherpur, pe o distanță de aproape 69 km, a fost studiat folosind o abordare ce integrează teledetecția și Sistemele informatice Geografice. Configurația albiei râului Manu a fost cartată pentru anul 1997 și 2010 folosind imaginile satelitare Landsat. Această analiză indică faptul că râul Manu este puternic meandrat, cu câteva sectoare critice, unde eroziunea este foarte accentuată, ducând la modificarea cursului. Această modificare este foarte intensă, în perioada menționată malul stâng deplasându-se cu 656 m, iar cel drept cu 628 m la Rajnagar, Moulvibazar. Acest studiu oferă cele mai recente și rapide dovezi privind geomorfologia fluvio-dinamică a râului Manu, care pot fi utilizate în conceperea și executarea schemelor pentru controlul eroziunii.

Cuvinte-cheie: *morfologie fluvială, deplasarea malurilor, teledetecție, SIG*

Introduction

River channel changes such as bank erosion, down cutting, and bank accretion are natural processes for an alluvial river (Yao et al., 2013). The nature, rates and causes of channel change have a particular relevance to the areas where high levels of disturbance threaten engineering structures and property (Gilvear et al., 1999) and are important for conserving the biodiversity of vegetation communities within the river corridor (Gilvear, 1993; Marston et al., 1995; Bravard et al., 1997). Regional developments such as sand mining, infrastructure construction on the riverbank, artificial cutoffs, bank revetment, reservoir construction and land use alterations have changed the natural geomorphologic dynamics of rivers (Surian 1999; Kesel 2003; Surian and Rinaldi 2003; Batalla et al., 2004; Vanacker et al., 2005; Wellmeyer et al., 2005). Change detection and quantification of erosion and deposition of riverbanks is such a study that is facilitated by application of RS, GIS and GPS. Remote sensing and GIS are widely used tools for detection and monitoring of changes of the physical environment (Andrea et al., 2001; Jensen, 2005; Stabel and Löffler, 2004; Ahmed, 2002; Twumasi and Merem, 2006, Deb, Das and Uddin, 2012, Aher, Bairagi and Deshmukh, 2012). In addition, the ability to quantify errors, which affect the precision of analytical results, is greatly improved by Gurnell et al., (1994). Important studies by Gurnell et al. (1994) and Gurnell (1997) have provided a valuable insight into the possibilities that GIS offers for river channel change analysis. Due to flood and riverbank erosion, Bangladesh loses a lot of land every year. During the monsoon, floods and flows of river water erode the bank.

In the winter, the water level of the river goes down and sandbanks get deposited alongside the riverbanks. Because of erosion and deposition of riverbanks, the country loses fertile land and gains sandbanks. Bangladesh Water Development Board (BWDB) reported that there were 140 km of river banks fully eroded and another 1345 km that were partially eroded by flood in 2007 (IRIN, 2008) which created more than US$ 75 million damages (Ahmed, 2006). The River Manu is located in the northeast