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THE STUDY OF THE NATURAL CHARACTERISTICS OF THE BASIN AS A FUNCTION OF FORECASTING EROSION AND DEPOSITION PROCESSES ON THE EXAMPLE OF THE SELECTED BASIN

Jugoslav Nikolić[1], Milena Nikolić** , Djordje Nikolić****
* Republic Hydro-Meteorological Institute of Serbia and Geographical Institute “Jovan Cvijić” SASA, Belgrade
** University of Pristina, Faculty of Natural Sciences, Kosovska Mitrovica,
*** UNION University - Nikola Tesla, Faculty of Ecology and Environmental Sciences, Belgrade

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Abstract: For an integral perception of the possibility of forecasting erosion-deposition processes and their consequences it is essential to analyze the factors of erosion and deposition. The attempt was made in the paper to analyze quantitative and qualitative impact of some of the most important factors of erosion-deposition processes. The analysis was performed through a multidisciplinary approach, on the example of the Zapadna Morava River upper basin. The methodology of research encompasses an application of the adequate knowledge from the areas of meteorology, geomorphology, hydrogeology, spatial planning, economic geography, forestry, hydrology and environmental protection. The analysis encompasses meteorological factors, terrain characteristics and anthropogenic factors. The importance of the analysis and forecasts of the investigated processes for the industry, economy, spatial planning and environmental protection was emphasized.

Key words: erosion, deposition, anthropogenic factors

Introduction

Erosion and deposition processes represent one of the most up-to-date problems of strategic importance for eco-systems, industry, economy, spatial planning and environmental protection. The forecast basis of these processes and their consequences represents an analysis of factors of influence.

In the run-off process, connection is obvious between erosion and deposition processes. The processes of erosion and deposition are related and commonly interacting. “Pure” erosion or “pure” deposition occurs in small areas. An area “without deposits”, or of “purely erosional landforms” is just a likely narrow zone on either side of a watershed.

[1] Correspondence to: jugnik@eunet.rs

Deposition and erosion are influenced by a large number of factors: geological, geomorphological, meteorological, as well as plant cover, hzdrological and anthropogenic factors. Certain factors have different, sometimes opposite effects on the processes of mechanical and chemical erosion, as well as on the process of deposition. Quantification of factors that primarily affect the erosion-deposition processes allows analysis/forecast of these processes. The basic objective of this paper is a quantitative and qualitative analysis of the most important factors of influence on erosion/deposition and an assessment - forecast of their integral effect on the case example of the Zapadna Morava river upper catchment.

Processes of mechanical and chemical erosion, and silt as a product of erosion processes, have a negative environmental aspects associated with the industry, more exactly waterpower engineering and economics. Deposit is the basic transporter of chemical and biological pollution of water currents. A significant portion of the polluting substances are transferred by suspended deposit particles impacting negatively river ecosystem and water quality for use in waterpower engineering (water-supply and irrigation).

Methodology of research

An analysis of the major factors of erosion/deposition processes was done through a multidisciplinary approach by applying the relevant knowledge from different scientific disciplines. The choice of a catchment area was performed without any conditional constraints.

By introducing quantitative geomorphological analysis in research procedure collecting qualitative new data was enabled (Mustafić et al, 2008). Input data are obtained through physical measurements and by carthometric way. First step in a research relates to formation of a relevant database from the domain of analysis/forecast on the basis of the grid-system. Geographic maps at scale 1:25,000 served to determine cartographic parameters. The selected catchment area is divided into unit squares of 1 km^2 resolution. Relevant data are updated for each field and used as a matrix in the quantitative analysis: lower left corner coordinates, maximum, minimum and mean altitudes, slope and woodiness (Dragićević, 2002). The amount of precipitation and other meteorological parameters are added by the method of numerical analysis to each elementary field obtained by standard measurements. The squares traversed by the watershed are subdivided into 100 smaller squares of 100x100 m, for a more accurate estimate in the catchment border area.

Among other things, a quantitative analysis was performed of the relief intensity ("potential energy of relief"), and slope, height zoning, atmospheric precipitation and woodiness. The results are presented carthographically, using the program package Surfer 10. In this way, areas are obtained where intensive erosion is expected, more exactly areas of expected deposition, which represent the basis for forecast of these processes. In addition, the qualitative analysis covered physical-geographic status, geologic setting and importance of artificial factors. The forecast of integral effect was verified in field observations.

In the methodology of precipitation analysis, series of monthly precipitations were used, obtained by standard measurements on meteorological stations, from the domain of analysis/forecast of erosion-deposition processes (Nikolić et al, 2005). The calculation of the evapotranspiration was performed by the application of the developed numerical model (Nikolić, 2002; Nikolić & Prohaska, 2005). The input of the model consisted of sufficiently long series of monthly quantities of the relevant meteorological parameters, which were routinely measured and commonly available.

Results

Basic physical-geographical conditions of the selected area

The subject of research relates to the Zapadna Morava river catchment upstream of the gauging station Miločaj Bridge, located about 9 km upstream of Kraljevo. The rectangle framing the catchment is between latitude 43º18.3' and 44º8.7' north, and longitude 19º30.7' and 20º42' east. For a correct analysis of the erosion-deposition processes adjacent to the watershed, the rectangle framing the catchment is enlarged a few kilometres on each side. This enlargement included precipitation measurements at major meteorological stations (Valjevo, Kragujevac, Kraljevo, Kopaonik, Sjenica and Zlatibor) near the catchment.

The Zapadna Morava river upper catchment area of 4655 km^2 falls into the category of "large catchments"'. In terms of the regional geography, this area includes parts of different entities: southwestern Šumadija, western Morava valley, northeastern Old Valachian highland and Valjevo ranges.

Surface configuration of the catchment is polygenetic (tectonic-fluvial, karst, abrasion, denudation) and multiphase in character. In geomorphological sense, configuration of the terrain studied belongs to terrains with genetic and morphologic diversity, which resulted from different formations: from clastic, organogenic and chemical sediments to regional metamorphic and contactmetamorphic rocks, and varied groups of magmatites. Its biogeographic diversity consists of tree communities, grass vegetation and field cultures. Hydrogeology is also diverse. In brief, the characteristic of the observed terrain is both surface and subsurface heterogeneity. Physical-geographical factors are important because they control the intensity of erosion- deposition processes.

Factors of erosion/deposition processes

Factors that have an impact on the erosion-deposition processes are divided into three categories: terrain characteristics, meteorological factors and anthropogenic factors.

Characteristics of a terrain are the characteristics of its drainage system and streams. Characteristics of a catchment or a drainage area are its morphologic, geometrical and elevation characteristics and other important factors are geology, vegetation and groundwater (Nikolić et al, 2007). Characteristics of streams mainly refer to their permeability.

The influence of vegetation on run-off, evapotranspiration, erosion and deposition is variable. For example, forests directly control processes of evapotranspiration and run-off through the forest/ground system albedo variation, through the influence on other energy balance components, on temperature regime, on wind in forest, turbulent wind entering woods and solar energy consumption in photosynthesis. The indirect control by forest is shallow soil freezing, or faster water percolation in forest during the winter. In contrast, run-off over the open land is greater in winter, because the deep-frozen soil acts as a water-bearing layer.

Meteorological factors include primarily precipitation and evapotranspiration effects on the run-off and erosion-deposition processes. The effect of precipitation is expressed through intensity and duration. Equal rainfall amounts of two different durations cause different run-offs and different effects on the erosion/deposition processes. Rainfall duration influence depends on the size and character of the catchment. Small catchments are more affected by storm rains than large ones.

In addition to rainfall and run-off, the evapotranspiration is a major quantity in the account of the water balance, on which depend the run-off as well as erosion and deposition processes (Nikić et al, 2009). Evapotranspiration depends primarily from the energy and dynamic conditions, whilst forest ecosystems and other plants, and the ground may largely modify the process. Trees and other types of vegetation biologically control, through surface resistance, the evapotranspiration and exert influence on the air current effect.

The process of the evapotranspiration is prevailing in the summer, which reduces the run-off, or the rainfall reaching stream. With the declining evapotranspiration in the autumn, groundwater storage is replenished and rainfalls run off more into the streams intensifying erosion and deposition.

Anthropogenic impacts relate primarily to the impacts of human activities on the processes of runoff, erosion and deposition through spatial planning: construction of embankments, stream-regulation works, dams and appurtenant structures, converting natural lands (pastures and woods) into agricultural fields, bogs into woods, and rapid urbanization with asphalt, concrete and other artificial impermeable surfaces. An additional form of anthropogenic impacts on erosion and deposition processes relates to climate modifiers through influence on precipitation regime, evapotranspiration and runoff.

Quantitative relief analysis

Relief digitalization is needed for the quantitative analysis /forecast of the erosion-deposition processes. By using digital data on Figure 1, two-dimensional survey of the terrain from the domain of analysis/forecast was given.

The recognizability of some landforms, such as Čačak lowland and other characteristic features, indicates accuracy of the relief digitalization. The relief has a significant influence on the development of erosion processes, especially in water erosion (Nikolić et al, 2007).

The relief energy of the Zapadna Morava river upper catchment

For the analysis of spatial intensity of erosion/deposition a map of "potential energy of relief" has significant importance, or vertical break down of relief in terms of the potential energy of ground determined by quantitative analysis elevation difference between the highest and the lowest points within the unit areas. Spatial distribution of the calculated potential relief energy of the Zapadna Morava river upper catchment is represented on Figure 2.

Spaces of high "relief energy" are the areas of expected erosion. Vice versa, spaces of low "energy" are areas of expected deposition. Contour lines of the "energy of relief" higher than 100 denote the areas well disposed to erosion, even more so that the positive value of "energy" is higher. Isolines represented by smaller values denote the areas of intensive deposition of the previously eroded material. Isolines also locate maximum (higher than +300, or darkest on the map) and minimum (less than 100, or most brightest on the map) relief intensities in the area. The analysis gains in importance if combined with field observations. Suitable conditions for deposition prevail in major river valleys, particularly in the Čačak and Požega lowland, and in Ovčar-Kablar gorge.

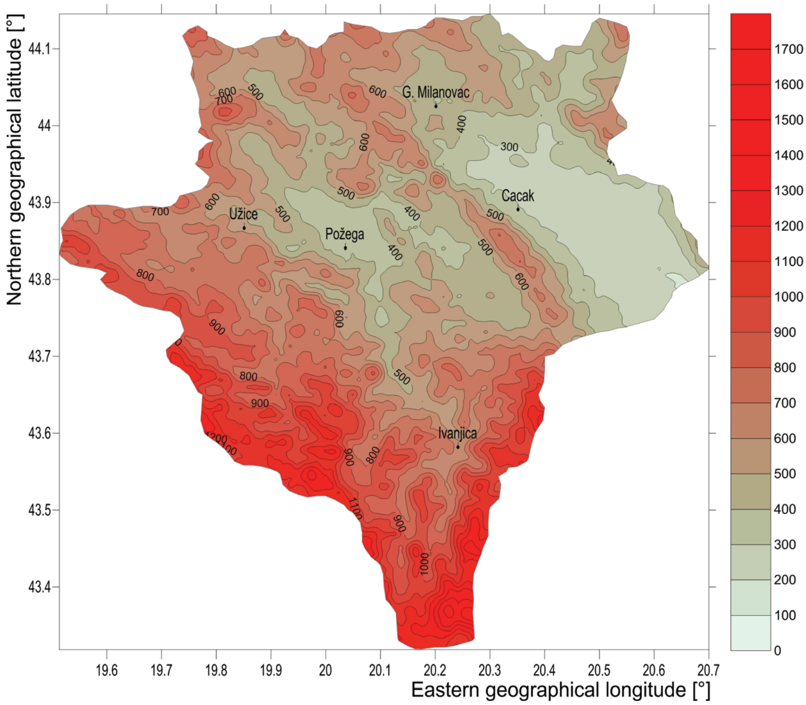

Figure 1. Two-dimensional survey of the Zapadna Morava river upper basin relief

Quantitative spatial analysis of ground slope

The slope of terrain is also a good indicator of erosion/deposition processes. It is defined by the angle that ground surface makes with the horizontal plane. Steep basin parts (5° or more) are potential areas of intensive erosion (enhanced, severe and very severe erosion), whereas less inclined lands are the likely areas of the eroded material deposition or mild erosion (average, low or erosion in traces). Whether this will be the actual situation depends on how effective are other factors, such as climate, vegetation, geology, human activities, and the like. This in turn suggests the necessity of both external and internal research. Figure 3 gives a spatial survey of the studied terrain slope.

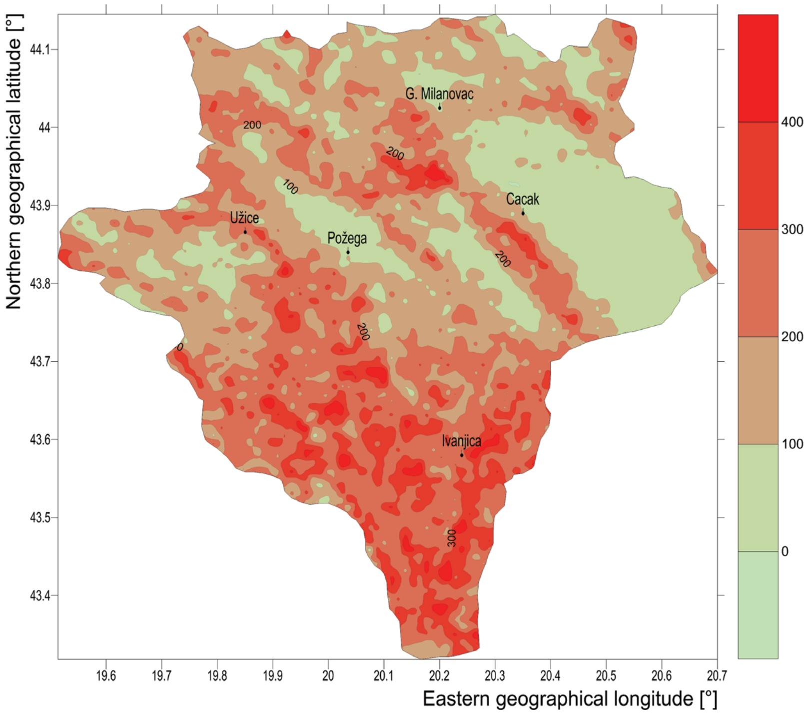

Figure 2. Distribution of "relief energy" of the Zapadna Morava river upper catchment

Slopes in the interval 0-5^0 are widespread on 16.23% of the territory of the basin, while slopes of 5-20^0 encompass 76.03% of the studied basin surface. Slopes of more than 20^0 are on remaining 7.74% of the territory of the studied Zapadna Morava river basin part. Generally, on arbitrary terrain with a large slope angle, the intensity of erosion processes is greatly increased.

Hypsometric analysis of the studied river basin

Hypsometric analysis provides the characteristics of high-altitude terrain. A schedule of the upper watershed of the Zapadna Morava river upper basin, obtained by numerical analysis, was given in Table 1.

This procedure obtains information about the representation of the mountainous terrain parts and the degree of predisposition for erosion processes. Depending on the altitude of the terrain is also a spatial planning and its proper use. Mean elevation of the explored catchment area, obtained by numerical analysis, stands at 730m.

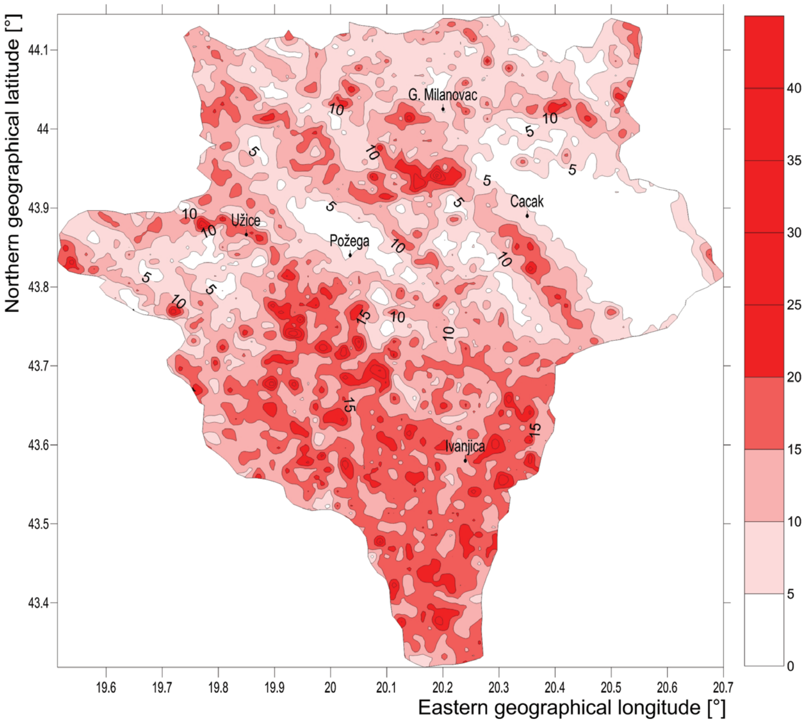

Figure 3. The survey of spatial distribution of slope angles of the Zapadna Morava river upper catchment

Terrain geology of the explored area

Geological substrates, primarily through the influence of water permeability of the terrain, modify the process of evapotranspiration, runoff and erosion-deposition processes (Nikolić et al, 2007; Nikolić et al, 2008). Geology of the study area is complex, composed of various Paleozoic metamorphic, Mesozoic sedimentary and magmatic, Neogene rocks and the newest, Quaternary sediments. Geological setting and structure are studied from the base geological map at scale 1:100,000.

Paleozoic rocks have a large distribution in the Moravica and Lužnica basins north of Užice and Požega. These are largely metamorphic sandstone, conglomerate, slate and phyllite.

Table 1. Elevation zones of the Zapadna Morava upper river basin in relation to “Miločajski most” profile

ALTITUDE ZONE (m)	AREA (km^2)	CUMULATIV AREA (km^2)	AREA PERCENT (%)
1800 - 1900	1.29	1.29	0.03
1700 - 1800	7.81	9.10	0.20
1600 - 1700	5.86	14.96	0.32
1500 - 1600	18.23	33.19	0.71
1400 - 1500	65.74	98.93	2.13
1300 - 1400	149.67	248.60	5.34
1200 - 1300	161.12	409.72	8.80
1100 - 1200	221.61	631.33	13.56
1000 – 1100	265.07	896.40	19.26
900 - 1000	373.92	1270.32	27.29
800 - 900	535.20	1805.52	38.79
700 - 800	635.75	2441.27	52.44
600 - 700	574.12	3015.39	64.78
500 - 600	577.73	3593.12	77.19
400 - 500	444.22	4037.34	86.73
300 - 400	281.44	4318.78	92.78
200 - 300	331.97	4650.75	99.91
100 - 200	4.20	**4654.95**	**100.00**

Triassic rocks are fully developed, dominantly in the southwestern, partly northern and central parts of the area. Lower Triassic consists of different rocks, mainly sand-shale and marl-slate series, and sandstone and limestone. Middle Triassic sedimentary rocks occur in two small areas. One is the Ovčar-Kablar gorge of the Banjska stream built up of thick carbonate rocks. The other, Đetinja-Veliki Rzav-Mali Rzav, is made up of Middle Triassic stratified, thick-bedded or massive dolomitic limestones over the Lower Triassic unit. Upper Triassic rocks are clean, massive limestones high on the Ovčar and Kablar mountains.

Jurassic rocks form wide continuous tracts of dominantly magmatic and less sedimentary rocks. These are chiefly serpentinite, gabbro, diabase and rocks of the diabase-chert formation. Serpentinite and harzburgite are extensive in the north and southwest of the study area. Gabbro and diabase form a narrow tract in the Kamenica valley. The diabase-chert formation of Jurassic age is located in two minor areas: the Veliki Rzav and the Mali Rzav, and the Đetinja valley to Bioska and Stapari.

The Cretaceous, widespread in the Bjelica basin and east of the Moravica, consists of conglomerate, sandstone, limestone and marl. Most abundant are massive limestone and flysch.

The Neogene is represented only by Miocene rocks, which are widespread in Neogene lake basins, such as Čačak-Kraljevo, Požega and Dobrinja basins. These deposits are sandstone, marl, shale, marly limestone, sand and clay. The Miocene includes volcanic rocks, largely in Gornja Trepča, dominantly quartz latite, latite and pyroclastics.

The newest deposits in the area are lake sediments, fluvial terraces, proluvium, diluvium and alluvium. Alluvial deposits are located in several places along rivers. The largest alluvial plain is deposits from the Zapadna Morava and there are minor deposits in the river valleys of Mali Rzav, Veliki Rzav, Đetinja, Skrapež, Moravica, Bjelica, Čemernica and smaller streams. The composition is always the same: gravel and sand, and less common coarse clay.

Geological structure of terrain significantly affects erosion processes by resistance and water permeability of rocks. Favorable conditions for the erosion exists at certain terrain areas that encompass non-resistant rocks, and unfavorable conditions exist at water permeable terrains (due to reduced surface runoff, increased infiltration and underground water runoff). Adverse conditions generally can be expected at carbonate rocks.

Woodiness of the explored area

It is known that permanent vegetation, such as forests, represent the most powerful forces opposed to the harmful effects of erosion. Forest ecosystems have a major impact on water runoff, development of erosion processes and deposits transport (Kostadinov, 2008).

Input data for quantitative analysis of woodiness are determined by carthometric way. The map in Figure 5 shows wood-coverage percent of the explored terrain. Forests are extensive (72.1%) in the Zapadna Morava catchment between the Bjelica and Kamenica and less (64%) in the upper reaches of the Moravica, upstream of Ivanjica. Wood-coverage is relatively small in the upper Đetinja, and the smallest between the Čemernica near Čačak and Miločaj near Kraljevo, compatible with the different geology and landforms.

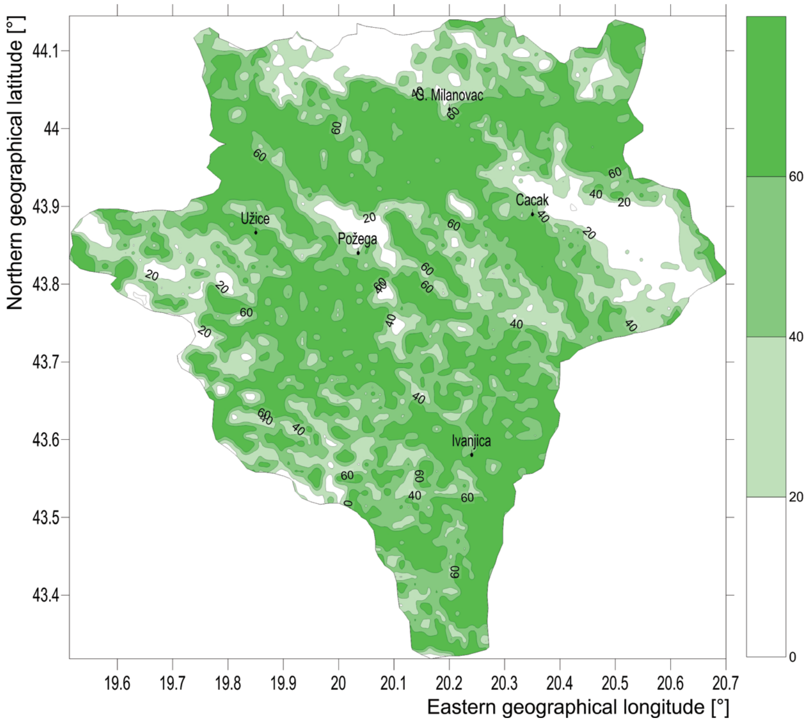

Figure 4. Wood-coverage percent for Zapadna Morava river upper basin

An increase of vegetation cover abates erosion. Conversely, destruction of vegetation cover opens the way to water and aeolian erosion. This reflects the special importance of forest ecosystems.

Zapadna Morava river upper catchment precipitation

Pluvial erosion, which is the most widespread, is one of the most important erosion processes. Distribution of the average precipitation sums, during the period 1981-2010, above the upper watershed of the Zapadna Morava river, is presented in Figure 4.

Average amounts of precipitation, less than 750 mm, are registered in Požega lowland and on the very south of the basin. Higher values of annual precipitation sums, those over 850 mm, can be seen in mountainous branches of Old Valachian-Raška highland.

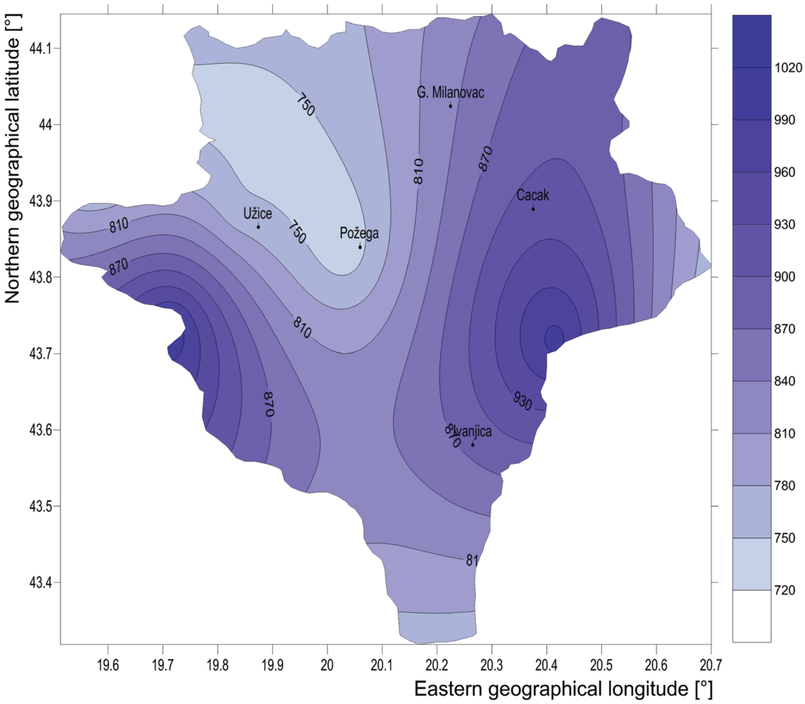

Figure 5. The average precipitation above the Zapadna Morava upper reaches
(Source of data: RHMI Serbia)

In addition to the annual amount, short rainfalls may be important for erosion. Erosion is sometimes more intensive in the regions with small amounts of precipitation, where most of the annual precipitation amount rapidly discharges within a short period of time. This analysis requires rainfall intensities, which are determined from pluviograph records, if such are available, as well as special samples for the analysis of silts with the goal of reducing mistakes (Manojlović et al, 2003; Dragićević et al, 2007).

In addition to destruction, removal and transport of ground surface, processes of erosion and deposition deteriorate river-water regime. As a result of erosion, there is a deposition of large amounts of silts that result in raised riverbed bottoms, while banks are lowered. That has a consequence of increased water levels and the occurrence of floods.

Precipitations discharged in the upper catchment of the Zapadna Morava river evaporate (66%) and there is a run off (34%). Generally, concerning forecast, increased precipitation leads to heavier erosion.

Anthropogenic impact

Qualitative analysis of the impact of anthropogenic factors is possible through a field research. By the exploration of lower parts of Moravica basin effects of the anthropogenic factors are visible and result from wood cutting, improper grazing of these terrains and disturbance of the equilibrium of natural erosion and denudation processes. Torrents, that result from storm rains, carry very large amounts of diluvium materials from slopes of this part of the basin. Characteristic examples of such processes are visible in the lowest course of the Megarski stream and in the Presjeka valley at the base of Mučanj Mountain.

Erosion processes, evidently enhanced by cutting forests, can be observed in the basin of Djetinja and Skrapez. On the other hand, terrains with a large slope are noticed that are relatively resistant to wash off processes, which is conditioned by afforestation. These processes of erosion, decelerated by the influence of anthropogenic factors, can be seen on steep slopes of Ovcar and Kablar.

Discussion

A potential areas of intensified erosion or deposition are obtained by quantitative analysis of parameters that primarily influence erosion-deposition processes. Verification of expected impact is performed through a field research. Given the large number of influencing factors, where some of them have the opposite effect, a need for field research arises that would carry out verification of the expected impact. The presented quantitative analysis gains in importance if combined with qualitative field research. That can be illustrated by a few characteristic examples:

1. Erosion processes in case of impermeable rocks should be most widespread in highly mountainous part of the Moravica basin where by quantitative analysis the greatest relief energy is obtained. Quantitative analysis showed that this is the strongest field of dissection and the largest energy relief. However, field research (Nikolić et al, 2007) has shown that these forms are very rare in this part of basin, which can be explained by terrain coverage with thick forests that prevent or substantially mitigate erosion and denudation of steep and high valley sides.

2. Erosion processes in the Moravica basin are fairly represented in the limestone ranges of Mučanj, Čemerno and Kukutnica, as well as in canyons or gorges of the Veliki Rzav and Mali Rzav. This is probably a consequence of prevailing influence of terrain slope, with collaboration of other factors such as

precipitation quantity, wind effect and chemical processes in these areas, but also the influence of man and improper grazing of these fields.

3. In the area of Đetinja and Skrapež basins a characteristic example of advanced erosion processes can be noticed on bases of schist, serpentine and sandstone. As a consequence of terrain wash off, riverbeds of above mentioned rivers are full of torrential deposits. Erosion processes of serious proportions have been enhanced by wood clearing. The Skrapež has transformed into a torrent intermittently filled in the spring and flooding Požega suburbs. The upper Čemernica is also an intermittent torrent.

4. Research in the field of Ovčar-Kablar gorge confirms favorable conditions for deposition in areas that are obtained by a theoretical quantitative analysis. A characteristic example relates to gorge lakes. Depositing of carried/pulled silt in the most upstream lake "Ovčar Banja" to some extent slowed down filing of downstream accumulation " Međuvršje ". Nevertheless, around 2/3 of useful accumulation of lake " Međuvršje " is already filled with silt. The intensive filling of the mentioned accumulations reduced their capability in terms of flood protection and caused unfavorable consequences from the aspect of water usage for the production of electrical energy (Figure 6).

Figure 6. Detail of Medjuvrsje lake deposition and vegetation appearance (Photo: J. Nikolić)

5. On steep slopes of Ovčar and Kablar characteristic erosion processes that are most visible in an area built of the diabase-chert formation rocks can be noticed. It is also noticeable that erosion processes very much depend on slope and woodiness of terrain. Erosion intensity is high or medium on majority of diabase-chert built slopes on the left side of the gorge. Heavily eroding are also

small areas on the right gorge side, especially in the site of the Međuvršje Dam. Other terrain parts, regardless of steep slopes, are relatively resistant to wash off process. Still, natural or artificial reforestation counteracts erosion.

Great intensity of erosion and sediment transport has resulted in the destruction of vegetation in mountainous areas, the occurrence of waste land, an imbalance of the ecosystem and environmental pollution. These processes have direct implications for spatial planning strategies, as well as on the economy and the economic effects of each area.

Conclusion

Many natural factors influence the processes of erosion and deposition, among which the most important are geological, meteorological, morphological, hydrological, biogeographical, as well as anthropogenic factors. Analysis, among other things, showed full justification of quantifying the most important parameters of the studied process. The basic feature of the quantitative analysis is that results are verifiable and have multiple applicability in practice. The results of quantitative analysis are very suitable for the perception of spatial distribution and intensity of erosion-deposition processes, forecast for their further development, planning of space use, planning and implementation of anti-erosion and anti-torrent measures, environmental protection, appraisal of certain economic effects and the like.

Use of the numerical model in determining evapotranspiration also proved correct and appropriate. Analysis/forecast of erosion process, sediment transport and its deposition has a significant impact on the environment. The direct impact of the erosion process is reflected in the loss of soil and vegetation on the slopes of the terrain and in an imbalance of the ecosystem, while indirect impact is reflected in mechanical pollution of water current and accumulation of sediment. The indirect effect of erosion process on the environment occurs through transport of erosional deposits by the hydrographic network and the process of sediment accumulation. The most significant effect of erosion process and sediment transport on the environment consists of the introduction of chemical and biological contaminants in river flows and water quality deterioration. Pollutants reach the hydrographic network through the process of washing away of eroded sediment. This means that the erosional deposition performs mechanical and chemical pollution of water and disturbs the ecological balance of water currents or lakes. Toxic metals are transmitted over the river flow, almost exclusively associated with a suspended sediment, as well as nitrogen, phosphorus and potassium because of erosion from agricultural areas in which the mineral fertilizers are entered.

Erosion /deposition processes have a negative environmental aspects associated with waterpower engineering. They represent constraining factor in spatial planning due to its negative impact and demand arranging erosional terrains through implementation of the entire complex of anti-erosion measures and anti-erosion works. On the other hand there are also positive effects of the erosion process and sediment creation because the sediments represent an important natural resource. There is undeniable importance of the gravel and sand as construction materials. Another potentially positive effect relates to the deposition of suspended sediment through river flooding in coastal area of river. Suspended sediment, created in the process of erosion of pedological terrain layer can increase fertility of land on which it is deposited in certain situations, although this is not always the case. All this has important economic implications.

With respect to complexity of the research in erosion/deposition processes, office research combined with field research is needed for verification. The methodology of analysis/forecast of the erosion/deposition factors, on the example of a basin with heterogeneous geological/geophysical conditions, produced a very good result. The applied methodology can be used for research of arbitrary terrains.

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