Impact of Land Use and Erosion on Radoviska Reka and Sushica Flooding in 2008

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Abstract

Torrent flood origin from the mountain, but consequences felt in the downstream sections. River basins are dynamic systems constituted by a complex arrangement of fluxes between the land and water environment. Land use pattern and planning has a observed influence on pick flow and sediments in small catchments. Case study was carried out on a Sushica and Radoviska Reka floods in December 2008. Damages by torrent Sushica were significant and much higher then Radoviska Reka damages. The aim of this study is to defined impact of geospatial factors on appearance of the flood wave and on the damages. A digital landscape model was developed consist of several layers needed for: analyze of discharge (DEM, slope, soil, geology, land cover/use, erosion, precipitation intensity), layers for analyze of reason for damages (urban plan, position of critical facilities, hydraulic structures in the bed, bridges) and analyze of municipality crises management body operation. Basin of Sushica (18,7km^2) is smaller then Radoviska Reka (53,8 km^2). All natural factors (slopes, drainage net, altitude difference, soil, geology, basin area..) contribute to the fact that Radoviska Reka is much more dangerous. Land cover favor Sushica (consist of arable land, degraded pastures and transitional woodland) while in the Radoviska Reka basin more then a half of the area is forest. Gavrilovic model was used for quantification of natural factors impact. Erosion coefficient is almost double higher in Sushica (Z=0,65) then in Radoviska Reka (Z=0,35). Precipitation value on critical day was 52,5 mm. Radoviska Reka was trained with various hydraulic structures (longitudinal and cross structure - check-dams for sediment retention etc.) Otherwise, there isn't any type of structure in Sushica bed. Urban plan in the center of the city (where Radoviska Reka pass) is adequate for flood damages minimizing, because there are two streets along the river bed that enable open corridor.. But the main problem for flooding was closure of the bed profile with sediment and improper built bridges (on the "Ancient Bridge" profile was 40% closed). Flood water didn't contain significant amount of sediments. Urban structure in the industrial part (where Sushica pass) was not adequate. There are installations closed to the torrent bed and these objects were highly damaged. As a result of, high erodibility of the basin and existence of wild landfill, significant amount of sediments closed the bridges, the first bridge collapsed, sediment was re-transported to the second bridge that was totally closed and water jump over the bridge and damaged infrastructure facilities. Municipality body for crises management operated but after the flood according to the national legislation and principles. Early warning system was not established but because of speed of onset of this hazard, practically there was no time for warning the citizens. It can be concluded that the main reason for flooding of the center by Radoviska Reka was improper bridges, while land cover/use pattern and erosion intensity together with the inadequate set up of industrial object and absence of flood control structures result in flood wave that cause significant damages.

***Key Words**: Flood, Torrent, debris flow, Radovis*

Introduction

Macedonia is vulnerable to flood both in terms of flood severity, or impact, and flood intensity, or strength. Flood contributed to 44 per cent of the hazards during the period 1989-2006. The number of events, affected population and economic losses are high due to flood during this period, indicating that the country is vulnerable to flood in terms of severity and intensity. The loss due to flood is very high, at USD 354 million. UNDP statistics show that 17,784 people were exposed to flood. The historic data prior to what is available in EM-DAT shows that Macedonia had two major floods during 1962 and 1979, with an estimated aggregate loss of about 7.2-7.4 % of GDP (1).

According to the Erosion Map od M (1993), exactly 1539 torrents are registered in Macedonia. These torrents made and make enormous damages to Macedonian economy. Number of killed or injured during these events is unknown. Normal consequence of these events besides flooding of the area and damages is huge quantity of sediments deposed in the downstream section. Mudflow and debris flows are typical for this type of torrents. All these streams origin from the mountain where there are high intensity erosion processes that result in large quantity of sediments even rocks with dimension up to 30 m^3. Radoviska Reka and Sushica are two of registered torrents that few time in the recent history (1916, 1973, 1982) flooded the town of Radovis.

On the 4th of December 2008, in the vicinity of the town of Radovis a storm followed by heavy rains occurred. According to preliminary reports the intensity of the rainfall was of 1mm/min. The high intensive rainfalls caused high runoff, which was especially prominent in the catchment areas of the rivers Sushica, Radoviska - Stara Reka, Injevska and Dedinska Reka as well as other smaller catchments in the surroundings. The floods originated from the hilly and mountainous areas, resulted with catastrophic discharge, unseen in the region for the last 50-60 years. On 04/12/2008, around 16:30 pm there was a significant change in the weather that literally created darkening the entire territory of the municipalities of Radovis and Konche. After 30 minutes of storm and thunders for no more than 40 minutes heavy rainfall started, and at around 17:30 in the river beds of river Radoviska Reka and river Sushica there was already a huge amount of water that was bringing along not only small fraction of sand and soil but the entire waste from landfill and what was left near the river and in a radius of 100 meters. The bridge on river Sushica, which was representing the old city exit and onto the path connecting M-6, under the pressure of the great torrent of water crashed, and water flowed of the river basin, in the urbanized part (complex of small businesses), the water carried large objects from the surrounding structures, cars, machines, trucks, building materials and everything that was found before the water flow, so water level was on the level of roof structures on existing buildings (2).

The flood had damaged 30% of the electricity network in the municipality, 4 submersible pumps with containers of water, where from the population in municipal was supplying drinking water, also were flooded. The cost of damages of the private sector was cca 3,4 million Euros. The damages of public goods haven't been estimated.

In the retrospective of assessment and reality with the undertaken measures will be concluded that 90% of the events during the flood could neither predict nor to set certain rules and principles for action.

This event is a subject of the analysis and the research in this study article. Research is focused on impact of land use and erosion processes in the basin on flooding.

Land use involves the management and modification of natural environment or wilderness. Land use and land management practices have a major impact on natural resources as well as natural hazards. Soil erosion is directly affected by land use and it changes.

Factors of erosion and surface runoff are common as follow: rainfalls (intensity and scope), soil and lithology characteristics (soil types, rock types, mechanical characteristics, porosity,) topographic characteristics (basin area, slopes, altitude difference, exposure.), land cover and land use.

Beside water discharge, that beside varying in value, and variation of quantity and dimension of sediment or ruins (result of erosion processes and transport factors) , consequence of flooding in urban area additionally depend on: stream bed characteristics (slope, hydraulic radius), structures in the steam bed, location of facilities in the potential flooded area, critical facilities.

Sushica and Radoviska Reka are typical torrents that origin from the mountain. According to the onset, flash flood happened in Radovis. According to the content of solid particles this flow can be characterized as debris flow.

Theoretical background

Stream characteristics

One of the earliest stream classification schemes was based on the watershed position of a river channel in the drainage network where headwater streams are called 1st order and the order increases when two like order streams converge (Strahler, 1952). Schumm (1977) also used watershed position to label streams by their role in sediment transport where headwaters are sources of material via erosion, mid-order streams mostly transport sediment, and large rivers are depositional zones (3)

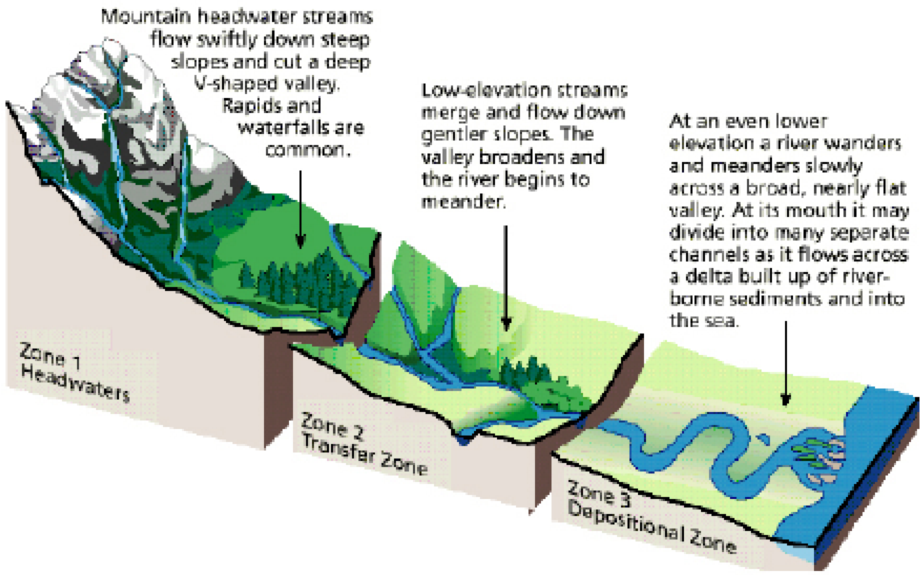
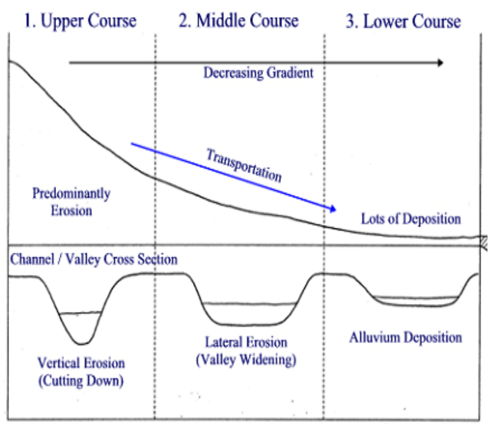


Figure 1: Longitudinal zones of a river corridor: Schumm, 1977; FISRWG, 1998, cited by Schiff R., et al (2006)

Above figure show a typical mountain stream. On the connection of transfer zone and depositional zone i.e. overcome from mountain to the valley are located settlements. Mountain steams usually have torrential character. Torrent flow is a fast, voluminous, or violent stream of water or other liquid.

Stream basins are dynamic systems constituted by a complex arrangement of fluxes between the land and water environment. There are essentially three interconnected fluxes, not only of water but also of sediments/nutrients and pollutants. Surface runoff caries sediments, nutrients and pollutants from the land through the river system, and as flooding occurs onto the floodplains. It is important to note that those fluxes are varying over time and space. Stream velocity depends on the slope of the stream bed, the degree of roughness of the stream bed, and the hydraulic radius. Streams carry dissolved ions as dissolved load, fine clay and silt particles as suspended load, and coarse sands and gravels as bed load. Fine particles will only remain suspended if flow is turbulent. Depend on the neighborhood area affected by heavy rain, stream carry additional material that could be transported as timbers, branches, woody structures, plastic particles and structures, even vehicles in extreme conditions. In this case, stream flow becomes debris flow. Debris flows are one of the most dangerous of all mass wasting events. They can occur suddenly and inundate entire towns in a matter of minutes. Debris flows are made of exactly what the name suggests: debris. This debris can include anything from the smallest mud particles to boulders, trees, cars, and parts of buildings. Debris flows occur when rain water begins to wash material from a slope or when water sheets off of a freshly burned stretch of land. (4)



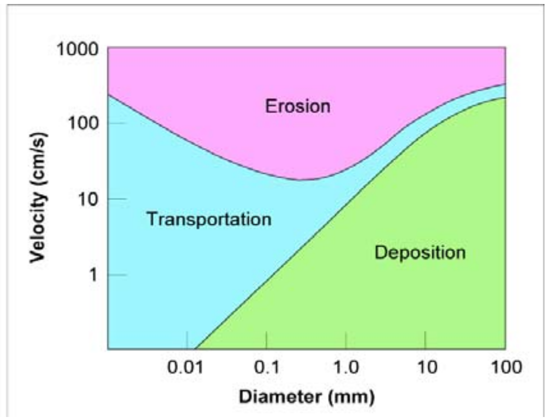
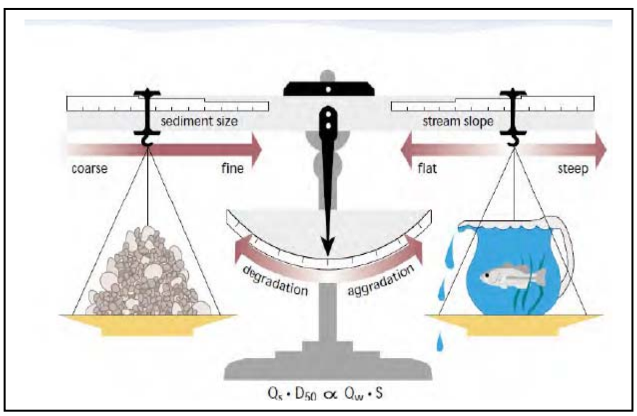


Figure 2. Long and cross bed profiles

Figure 3. Hjulstrom's Diagram

Generally in the upper pat of the long profile there is more turbulence, lots of bed load and lots of roughness and fiction. As more steams join the river, roughness decrease, discharge and velocity increases and the erosive power of bed load will decrease. As a result the gradient of the rive will generally decrease creating a concave long profile with distance down stream and deposition seves to enhance this phenomenon further. Erosion in the upper valley is generally straight down into the bed, and vertical, helping to keep gradient steep. In the lower reaches erosion is lateral or side to side, reducing gradient and further enhancing the concave long profile. Base level is the lowest level to which erosion by running water can take place. Grade is the concept of a rive being in equilibrium, with balance between the rate of erosion and deposition. This balance is constantly upset by changes in discharge and sediment load, and can alter over long periods of tie because of changes in base level. Also, river can change across their channels, where variable discharges and loads cause channels to shift position and shape to adjust to these changing characteristics. (5)

Hjulstrom's Diagram plots two curves representing 1) the minimum stream velocity required to erode sediments of varying sizes from the stream bed, and 2) the minimum velocity required to continue to transport sediments of varying sizes. Notice that for coarser sediments (sand and gravel) it takes just a little higher velocity to initially erode particles than it takes to continue to transport them. For small particles (clay and silt) considerably higher velocities are required for erosion than for transportation because these finer particles have cohesion resulting from electrostatic attractions. Think of how sticky wet mud is. (6))



If the slope is too gentle and velocity is too slow to transport the sediments being supplied by weathering and erosion, the sediments will pile up. This increases the gradient which causes the water to flow faster, which increases erosion and transport, which then reduces the gradient. In the lower reaches of a stream, where the discharge is greater, since friction is less, the stream need not be so steep to transport the load. .(7)

Figure 4: Factors affecting channel equilibrium. At equilibrium, slow and flow balance the size and quantity of sediment particles the stream moves (Rosgen (1966) from Lane (1955) cited by Andeson K. (8)

Land use and hydrological elements

Land management is considered one of the essential keys to identify and implement adaptation strategies to natural hazards (including, but not limited to, flood prevention) while preserving the sustainability of EU regional developments (9)

Natural geomorphologic processes influence stream basin fluxes to varying degrees. For instance, natural phenomena such as land slides can have a significant influence on the sediment loads of adjacent water courses. Those sediments are deposited in the drainage systems, reducing the conveyance capacity of the channel and reservoirs. An essential but on the policy level frequently neglected consideration in the assessment of land use effects on those fluxes is scale. While some pollution effects, such as pesticides and heavy metals can be traced on larger scales, the relationship between land-use and flow variables becomes increasingly difficult to establish with increasing spatial scale. For example the effects of certain land cover changes on sediment load and peak flows can be established in smaller watersheds but on basin scales this is scientifically not sufficiently explored territory. On that scales there are no simple cause and effect relationships but the system that influences those parameters on larger scales becomes highly complex. Table illustrates these points by providing an indication of observable impacts of land use on various parameters for different spatial scales. The qualifications provided in later parts of this publication should be read in light of that. (10).

Table 1. Spatial dimension of land use effects (FAO, 2002, cited in FAO 2007)

Impact	Basin size [km^2]						
	0.1	1	10	100	1 000	10 000	100 000
Average flow	x	x	x	x	-	-	-
Peak flow	x	x	x	x	-	-	-
Base flow	x	x	x	x	-	-	-
Groundwater recharge	x	x	x	x	-	-	-
Sediment load	x	x	x	x	-	-	-
Nutrients	x	x	x	x	x	-	-
Organic matter	x	x	x	x	-	-	-
Pathogens	x	x	x	-	-	-	-
Salinity	x	x	x	x	x	x	x
Pesticides	x	x	x	x	x	x	x
Heavy metals	x	x	x	x	x	x	x
Thermal regime	x	x	-	-	-	-	-

Legend: x = Obervable impact; - = no observable impact

Hydrological responses to rainfall strongly depend on local characteristics of soil, such as water storage capacity and infiltration rates. The type and density of vegetation cover and land-use characteristics are also important to understand hydrologic response to rainfall. Environmental degradation coupled with uncontrolled urban development in high-risk zones, such as historical inundation plains and at the base of mountain ranges, leads to an increased vulnerability of those communities on the floodplains to catastrophic events. (10).

As civilization progresses, human activities gradually encroach on the natural environment altering the dynamic equilibrium of the hydrological cycle and initiating new processes during rainfall events. It is now well accepted that there exists causal links between environmental degradation, land-use and vulnerability to disaster. In physical terms, for instance, flash floods are considered to be fast onset disasters, but the root cause may reside in a historically progressive process of environmental degradation and unsustainable land-use that affects the hydrological response and the impact of the flood. (10)

Some floods origin from the mountainous regions and their consequences are usually felt in downstream sections like in a case of Radovis flooding. Human intervention can also cause natural disasters where they weren't before. Human alterations of the catchment area can significantly contribute to changes to all those processes through large scale land use changes and land-use practices. It is important to emphasize and to understand that human activities can increase the frequency and intensity of natural disasters, but also to reduce the effect of occurrence of damage to the timely and proper placement of things. Overall analysis and review of the event happened on 12/04/2008 in Radovis is a good basis to consider the consequences of these human actions. (11)

Erosion and runoff have not only on-site effects, mainly soil degradation, but also off-site effects
On-site erosion effects affecting farmers and create losses in eroded areas:

- Losses of water, fertilizers and pesticides
- Immediate production loss
- Loss of arable land
- Long-term productivity loss

Off-site - or downstream – erosion effects-damage usually affect townspeople:

- Deterioration in water quality (pollution of rivers, death of fish, silting up of reservoirs..
- Increase in suspended load (SL) - higher costs for drinking water
- Flooding of inhabited areas - mud flows, debris flow, sanded up ditches
- Rise in peak flows of rivers - destruction of structural works, bridges, etc.

On-site erosion effects create soil degradation that is a serious problem only for some smallholders. Off-site damage is much more costly, and forces the State to act.

While abundant runoff at certain times of year increases peak discharge into spillways, it also reduces supplies to groundwater and the rate of low-water flow. On the one hand, it causes downstream sediment on the river bed and banks to be recycled downstream - an erosion phenomenon. Peak flood sediment loads also cause damage, leaving torrential mud flows at the bottom of fields, in ditches, on roads and in cellars. Once the peak flood is over, considerable amounts of sediment are deposited in lakes, rivers, canals and harbours. (12).

Aims, objectives and research methodology

Main aim of this study is to define impact of land use and erosion processes on peak flow and flooding of the Radovis city during event happened on 4.12. 2008.

A comparative study was carried out for Sushica and Radoviska Reka cases. These two streams flooded the city of Radovis, but consequences of flooding were different. Objectives of this study are:

- defining hydrological parameters of the basins,
- defining land cove/use, defining erosion processes,
- defining urban parameters including construction in urban area
- comparison of these elements and flood consequences
- creating what-if scenario: impact of land cover/use changes on erosion and peak flow.

Research was carried out in few phases:

- collecting various data (paper, analog, digital, various geospatial factors – natural and socioeconomic;
- field recognition, mapping, measuring (conditions in the basins and steam beds, land use on the basins, updating of preliminary paper data, measuring stream bed characteristics etc.),
- creation of geospatial database for all erosion and discharge factors, (scanning, georeferencing, vector data, raster data, attribute tables, etc)
- numerical graphical modeling (reclassifying of basic layers, rasterization, geospatial analyses, modeling erosion, runoff and peak flow)
- comparative analyze and interpretation of result done for both basins
- interpretation of results from what-if scenario model.

Study region characteristics

Sushica and Radoviska Reka are located in the municipality of Radovis, in the south-eastern region of the Republic of Macedonia between two larger and more developed municipalities, municipality of Strumica and Stip. Sushica and Radoviska Reka are tributaries of Stara Reka (Strumica). They belong to Strumica river basin and transboundary Struma river basin (Macedonia, Bulgaria, Greece).

Figure 5. Location of the study area

Municipality of Radovis together with municipality of Konce, represent a sub-region where few branch offices of national administration or public institutions have competences (branch offices of ministries, branch offices of public institutions fo managing forests, pastures.). The following description concerns this sub-region and target basins. The territory of the sub-region lies between the mountain range of Plackovica on the north and northeast, on south and southeast is Strumica area, on southwest is Smrdeshnik Mountain and northwest is the gorge of Mladenska Reka. The municipality with an area of 608 km^2 with a total population of 28.812 people has a total of 25 settlements. Land configuration is more hilly and mountainous, with a portion of flat arable land. Konce is rural municipality having 3690 inhabitants and 11 settlements. The altitude varies from 290 m.a.s.l. (in the valley) up to 1707 m.a.s.l..

Relief is dominantly hilly – mountain and mountain (75%) with moderate to steep slopes, generally exposed to southeast and is favorable for develop of various erosion processes and surface runoff. Sushica and Radoviska Reka basins belong full to hilly-mountain area. An average slope of Radoviska Basin is 29%, while Sushica basin 12,7%. Radoviska Reka altitude varies from 390 up to 1700, while Sushica basin from 390 up to 900 m a.s.l..

Lithology structure is various represent by rocks from various ages: Archaic, Paleozoic, Mesozoic, Cenozoic. Dominant rock types in Sushica basins are gneisses (67%) and alluvium (22%) while mica schist and amphibolites are presented lower. Radoviska basin is more heterogeneous. Dominant rocks are mica schist, leptinolit, phyllite, carbonate schist and gneiss. Participation of other rock types is lower. Soil pattern is heterogeneous too. Chromic cambisol, colluvial soil, ranker- regosol and lithosol represent Sushica basin soil pattern. Colluvial soils cover lowest pat of Radoviska Reka basin, chromic cambisol hilly area, eutric and dystric cambisol cover mountain area while ranker the highest pat of the basin. Generally lithology and soil pattern are favorable for develop of various erosion processes and burdening of surface flow with solid particles. .

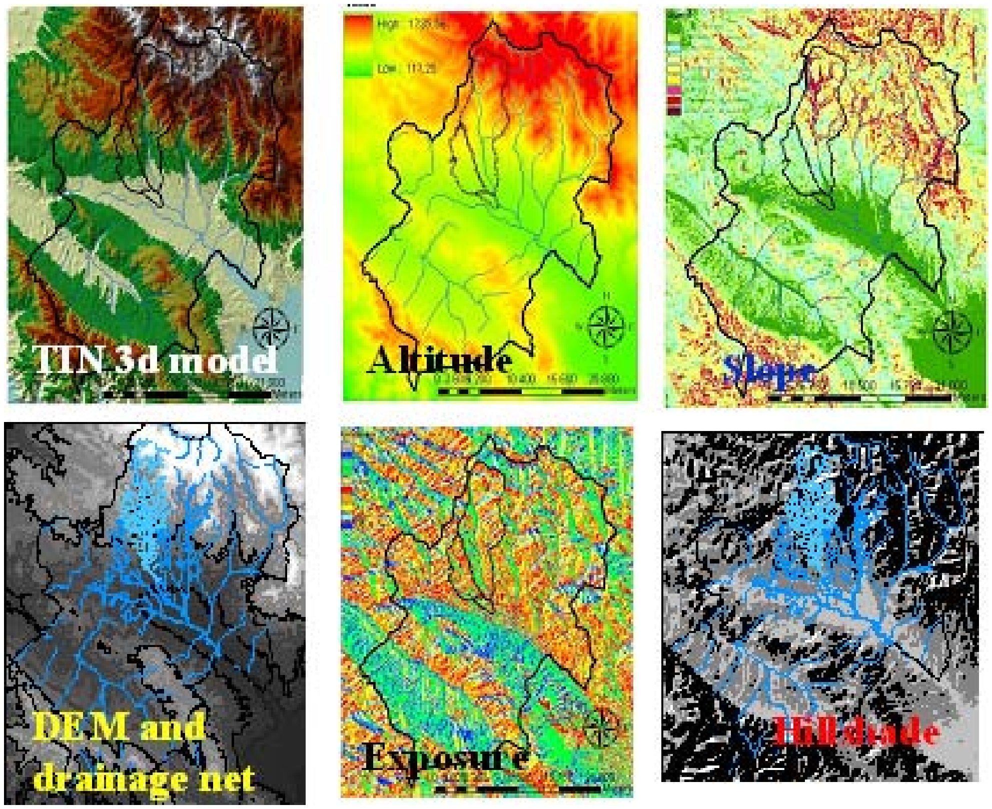


Figure 6. Topography characteristics of the sub-region

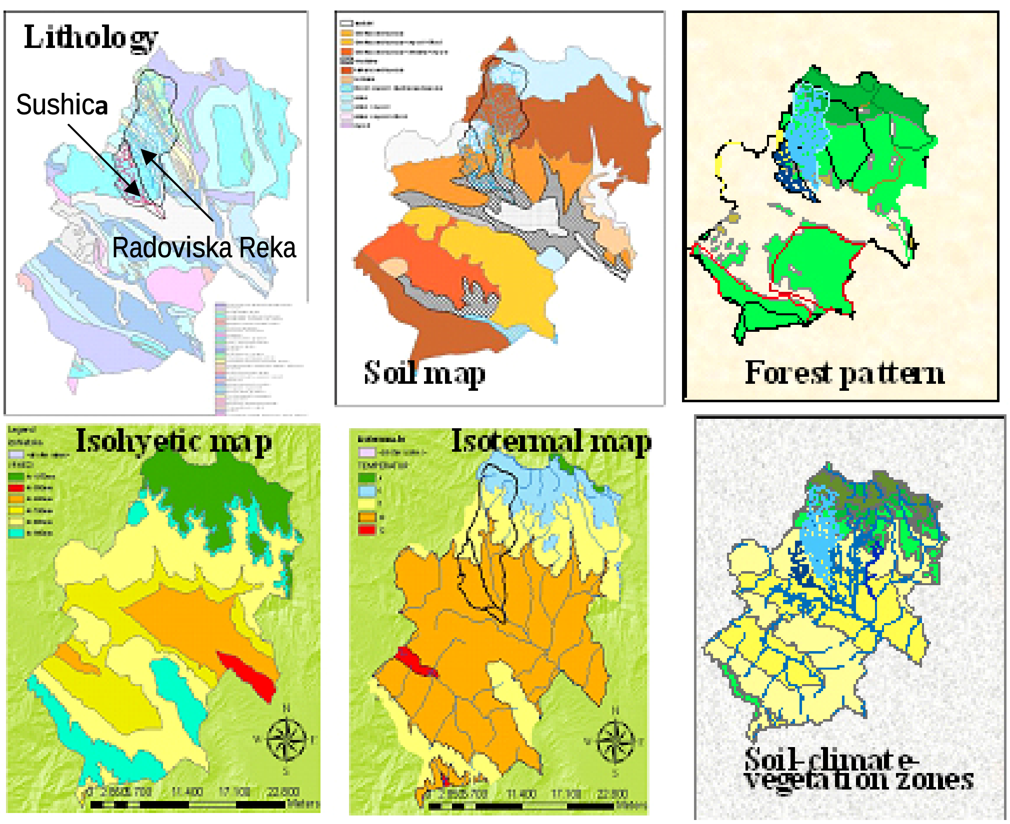


Figure 7. Other natural characteristics of the sub-region

Depend on the altitude and geo-position, precipitation in the sub-region vary from 450 – 950 mm. while temperature from 4 – 12^{o}C. Generally, climate in the region is arid – semiarid. Two rainfall gauge station are located in Radoviska Reka basin: Kozbunar (1050 m a.s.l., represent of mountain area) and Radovis (390 m a.s.l.). Additionally 2 gauge stations are located in the sub-region but out of the target basins: Podares and Kalugerica. Mean annual sum of precipitation on both gauge stations ae as follow: GS: Kozbunar for the period 1961-2010 is 686,5 mm and vary from 398,5 mm up to 1116 mm., GS Radovis for the period 1951-2010 is 471,5 mm and vary from 204,5 mm up to 899 mm. Period from 1981 to 1990 was extremely dry period. Mean annual sum of precipitation in this period was 293 mm, while 5 times (1982, 1984, 1986, 1987, 1988) total annual sum of rainfalls was bellow 250 mm. Very interest fact is that in the year 1982, was recorded the absolute minimum of annual sum of precipitation on GS Radovis (204,5 mm), while value on GS Kozbunar (569 mm) was bellow the average, but Radoviska Reka flooded the city of Radovis. Extreme dry conditions influenced land cover especially forest cover (when were recorded massive attack of pest and disease and forest die back) as well as soil structure (destroying of soil characteristics). It was a reason that rainfalls of 43 mm, caused high erosion processes and significant surface runoff that finally result in flooding of the city of Radovis.

Forest pattern in the mountain region is various. Broadleaved forest species are dominant: especially various oak communities and beech communities too. This forest pattern is represented in Radoviska Reka basin, while in Sushica basin almost has no forest. Pat of the forests is degraded as a result of natural conditions and human activities in deep past. According to the Filipovski- Rizovski-Ristovski classification, Radoviska Reka basin belong to 5 soil-climate-vegetation zones, but dominant zones are continental sub-Mediterranean and warm continental zone.

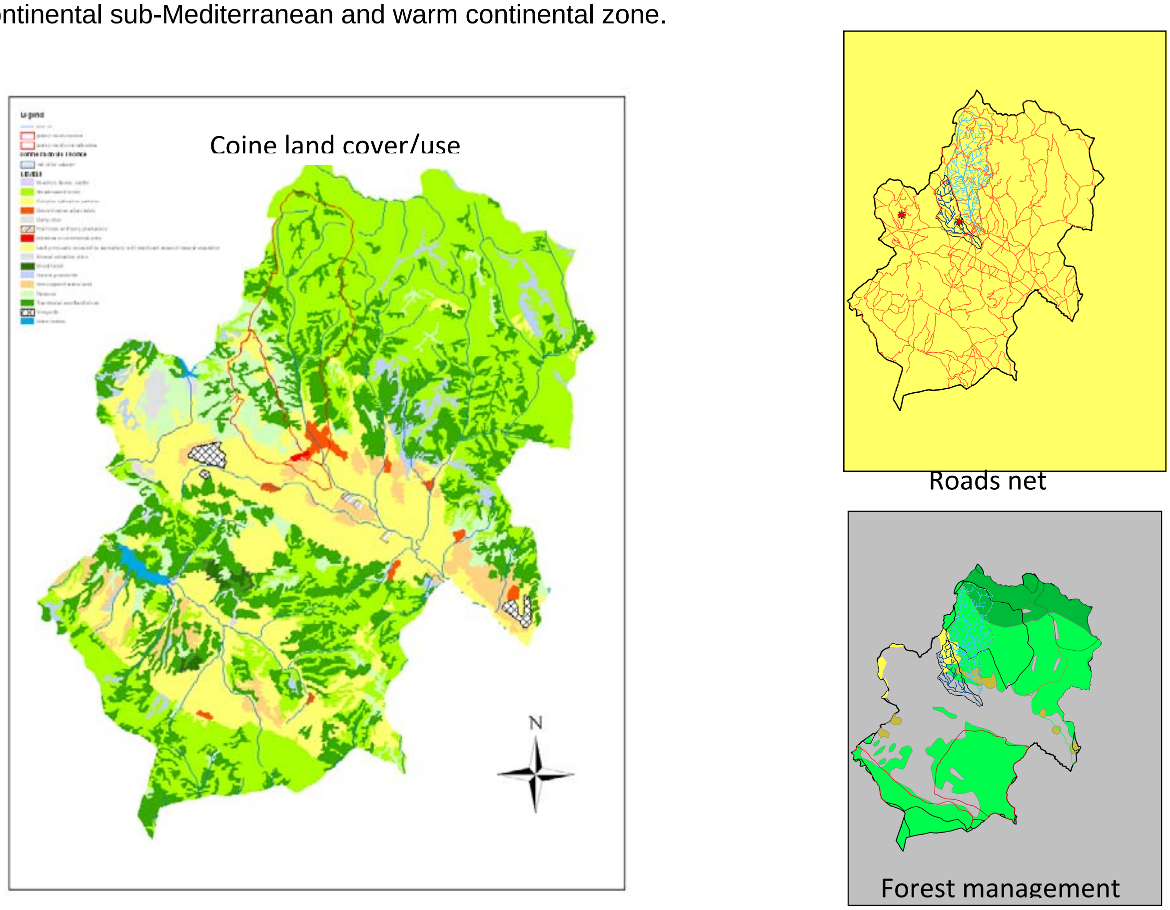


Figure 8. Socioeconomic characteristics (land cover, road infrastructure, forest management units)

Results

Land cover/use

Land cover/use pattern was defined according to CORINE LCU classification.

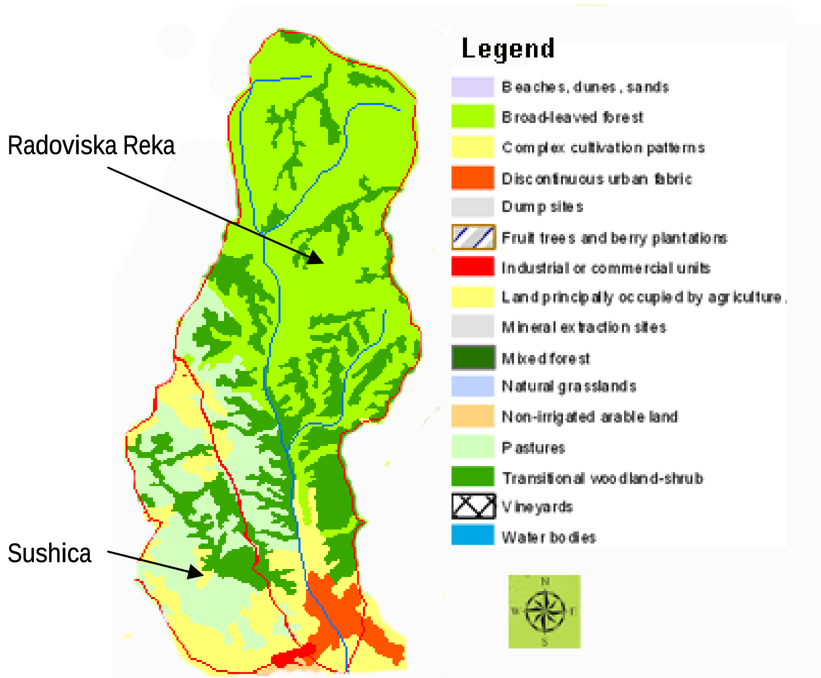


Figure 9. Land cover/use map of Sushica and Radoviska Reka

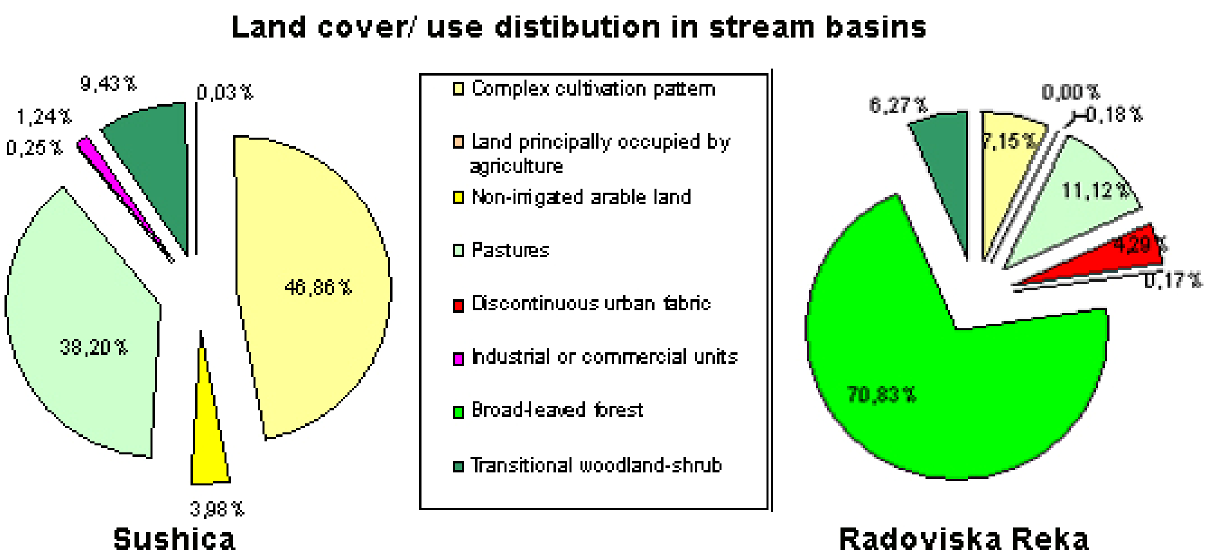


Figure 10. Land cover/use distribution of Sushica and Radoviska Reka

Generally Radoviska Reka basin is well covered. Participation of 70% of broadleaved forest enable good soil coverage, good protection from rainfall bombing. Oak and beech forest accept 13-15 % of water as interception, enable soil infiltration and minimized runoff especially in vegetation period. Role of transitional woodland and pastures in hydrological processes is worsted then forest cover. Soil is not well protected from rainfall “bombing” i.e splash/sheet erosion. Beside it, runoff coefficient on this type of land could achieve 0,6. Participation of open space as artificial land (urban area, commercial, industrial..) and agricultural land (arable land etc.) enable maximal erosion and runoff depend on other terrain characteristics. This type of land cove type s is presented with 13%.

On the other hand, Sushica basin is almost “bare” and open. Participation of forest cover is almost 0%. Participation of pastures an transitional woodland is almost 48%. Other pats of the basin belong to open area: urban and agricultural arable land. This land cover /use distribution is very favorable for development of high intensity erosion processes and high surface runoff.

Erosion intensity

Erosion processes wee evaluated using Erosion Potential Model (EPM) and Classification. According to EPM, erosion processes are categorized in 5 categories: very low, low, medium, strong, very strong. According to EPM, erosion coefficient - Z - vary from 0,05 (forest on flat areas) up to 1,50 (high intensity gully or fluvial erosion). IN a case of extreme events that generate high quantity of material that is a subject of transport downstream (large landslide, landfall, badland etc), erosive coefficient – Z - could be higher (even 2,5).

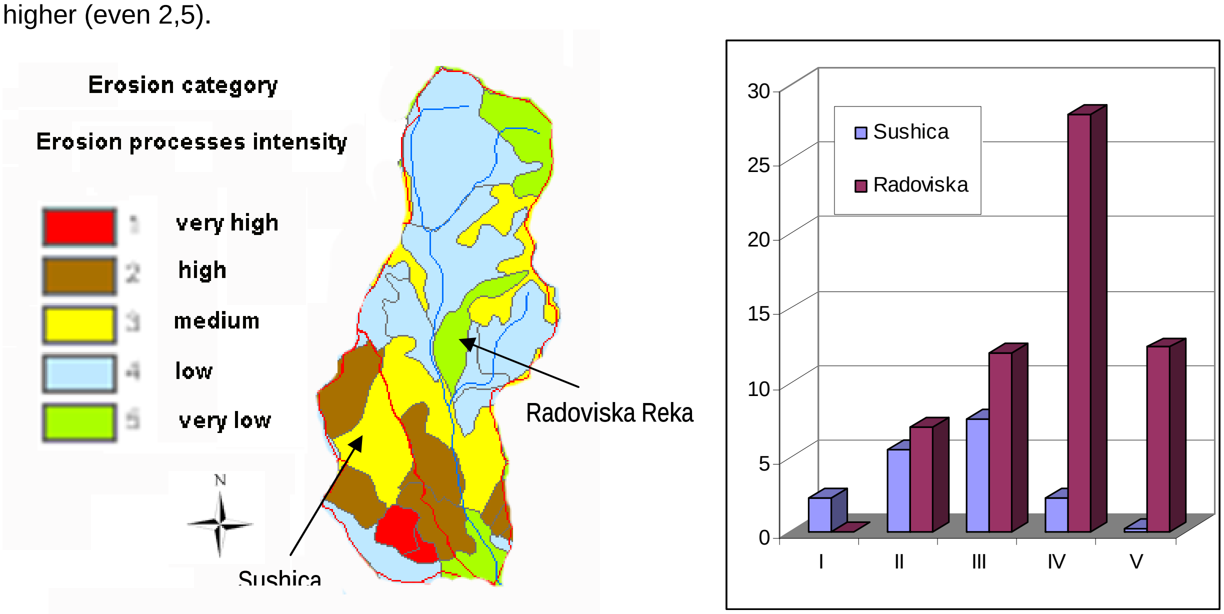


Figure 11. Erosion map and erosion distribution of Sushica and Radoviska Reka

Sushica basin is dominantly encompassed by higher erosion processes (1-3 categories). Low medium processes are represented on very small parts of the basin. Higher erosion processes are represented in second pat of the Radoviska Reka basin especially in the downstream part near the human settlements and influence and partially on the highland (again caused by human). Almost half of the basin is represented with low and very low erosion processes. Basin of Sushica is much more erodible then Radoviska Reka basin. It impact on production of erosive material.

Participation of various erosion processes by intensity is numerically evaluated using EPM values and erosion coefficient - Z. Using Arc GIS tools, erosion coefficient – Z - is calculated and results are as follow:. Z = 0,66 (Sushica), Z = 0,35 (Radoviska Reka).

According to the same methodology (EPM), total annual quantity of erosive material is as follow:
E = 1323 m^3/km^2 (Sushica) and E = 629 m^3/km^2 (Radoviska Reka).

Hydrological factors of the basins

Factors that affect surface runoff are as follow:

- Basin characteristics (size, shape, slope, land use (cover), soil type, antecedent conditions);
- Storm characteristics (storm intensity and total depth, storm duration, spatial variation, movement);
- Hydrography (size, shape, degree of development of the flow system or drainage density).

Various hydrological models content parameters for almost all of these elements.

One of the simplest parametric model is Gavrilovic model that is regional model developed after long-tem measuring in South Serbia and natural conditions in Macedonia especially in central and eastern part of RM are similar to those where this model was developed.

$\mathbf{Q = A\ S_1\ S_2\ W}\ \sqrt{2gDF}$ where:

Q – maximal discharge (peak flow) m^3/s

A – watershed shape coefficient

A = 0,195 S/L

S – perimeter length ; L – steam bed length

S_1 – coeff. of land cover, vary from 0,6 (good forest) – 1 (bare land)

S_2 – coeff. of permeability, vary from 0,4 (high porous soil) – 1 (impermeable soil and magmatic rocks)

W - retention coefficient in a case of snowmelt and high intensity rainfalls

W = h (15 – 22h $\sqrt{L}$), h – high intensity rainfall [mm]

$\sqrt{2gDF}$ - energetic potential of the basin during flow in a case of high intensity rainfalls

g – ground acceleration = 9,81 m/s^2

D = Hsr – Hul – mean altitude difference (m) ,

Hsr – mean basin altitude, Hul-altitude of profile in the city Radovis

F – basin area (km^2)

From developed basic layers for the region of Radovis-Konce, using adequate tool in Ac GIS were extracted basins of Sushica and Radoviska Reka. It means that after this operation were developed digital landscape models of the basins. That was a base for further modeling.

Topographic characteristics were calculated directly using DEM and developed layers. Basin area, perimeter length and stream bed length were calculated from developed suitable layers (basin watershed, steam network). Mean altitude and altitude of the profile were calculated from the DEM (30 m resolution).

Coefficient S_1 and S_2 were calculated on a base of soil/lithology layer and COINE land cover/use (level 3) layer. Within the attribute tables of each layer, was added new column and for each ID (type) was put numerical value using suitable tables by Gavrilovic

Rainfall depth was used for both basins the same value P = 52,5 mm. This value is near the 1% high intensity value (60 mm) estimated by Skoklevski and Todorovski 1993 (14).

After that was estimated maximal discharge (peak flow) of this storm event and specific discharge.

Table 2. Hydrological characteristics of target basins and maximal discharge calculation (according to Gavrilovic methodology)

Parameter	Measuring unit	Sushica	Radoviska Reka
F	km^2	18,7	54,38
S	km	22	35
L	km	9,1	15
Hsr	m	556	1011
Hul	m	389	395,6
D	m	167	615,4
g	m/s^2	9,81	9,81
h	mm	0,0525	0,0525
A		0,47	0,46
S_1		0,83	0,915
S_2		0,84	0,71
W	m^2/km^2	0,679	0,666
2gDF	m.km/s	261,934	810,304
Q_{max}	m^3/s	58,49	159,49
Q_{sp}	$m^2/s.\ km^2$	3,13	2,93

Basin area of Radoviska Reka is almost 3 times bigger and estimated peak flow is 2,7 times higher.

Factors affecting erodibility are similar. Erosion coefficient $Z = \gamma\ Xa\ (\varphi + \sqrt{Jsr})$ where:

Z – erosion coefficient

γ – coefficient of soil/rock resistance on erosion, vary from 0,25 (magmatic rocks), 0,8 (cambisol), .0 (podzolic soils, gneiss, mica schist) up to 2,0 (sand and gravel).

Xa – coefficient of land cove /use including erosion an torrent control measures, vary from 0,05 (good forest cover) , 0,6 (mountain grasslands/pastures) up to 1 (bare land),

φ – coefficient of visible erosion processes, vary from 0,1 (good forest, no visible erosion) up to 1(extreme erosion processes, badland, landslide, ..)

Js – mean basin slope (%)

Table 3. Erodibility parameters of target basins and maximal discharge calculation

Parameter	Sign	Sushica	Radoviska Reka
coefficient of soil/rock resistance on erosion	γ	1,094	0,987
coefficient of land cove /use including erosion an torrent control measures	Xa	0,66	0,23
mean basin slope	Jsr	12,7	29,11
erosion coefficient	Z	0,65	0,37

Erosion intensity in Sushica basin is almost double higher.

Because all main parameters for calculation discharge: A, S, S_2, W and 2gDF, are right proportional, we can compare them directly. Watershed shape coefficient (A) and retention coefficient in a case of snowmelt and high intensity rainfalls (W) are almost the same.
Coefficient. of permeability (S_2) is slight higher (0,84 vs 0,71), while and energetic potential of the basin during flow in a case of high intensity rainfalls ($\sqrt{2gDF}$) is almost 3 times higher for Radoviska Rea basin. The only parameter that is higher for Sushica basin is land cover/use coefficient (0,915 vs 0,83).

Related to erodibility parameters, relation of these parameter is equal. Coefficient of soil/rock resistance on erosion (γ) is almost the same (1,09 vs 0,98). Mean basin slope is significantly higher in Radoviska basin (29,1 vs 12,7). On the other hand, coefficient of land cove /use including erosion an torrent control measures (Xa) is almost 3 times higher in Sushica basin.

Land cover is the only parameter of Sushica basin that is higher then in the Radoviska Reka basins. While as a peak flow affecting factor is slightly higher, as erodible factor is significantly higher. It means that Sushica basin is prone to producing significant quantities of erosive material.

In that case, flow in Sushica is burden with significant quantity of solid material. Transport capacity depend on discharge, flow velocity and stream bed morphology. It is calculated that Sushica generate 1323 m^3/km^2 erosive material annually, but on the profile city Radovis, 463 m^3/km^2 transported sediment is calculated. Radoviska Reka generates 629 m^3/km^2 of sediment, but on the profile city Radovis, 390 m^3/km^2 transported sediment is calculated.

Drainage net and stream bed morphology

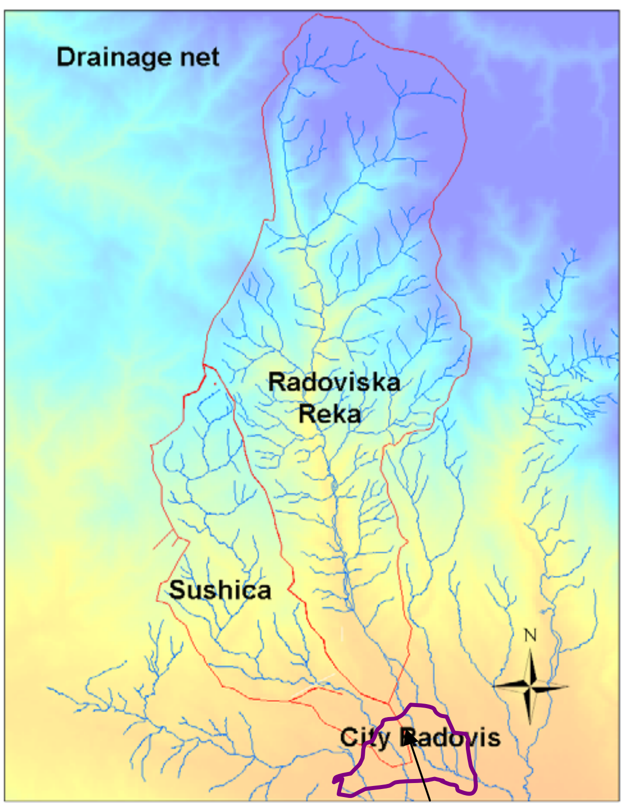


Figure 12. Drainage net of Sushica and Radoviska Reka
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Both streams have mountain character with steep streambed slope.

Sushica is a hilly-mountain basin, but as a result of natural geological erosion processes in deep past there is significant number of carved drainage lines. Mean steam bed slope is 4,56%. Streambed slope of Sushica vary from 10,08% in the upper part of the basin, 6,8%, 4,97%, 2,54%, 2,32% up to 1,12% in the city of Radovis,

Radoviska Reka is typical mountain stream. Drainage net is high developed with a lot of small streams – tributaries. Mean steam bed slope is 6,30%.Streambed slope of Radoviska Reka vary from 19,5% in the high mountain part of the basin. 11,3% 4,01%, 2,1%, up to 1,80% in the city of Radovis,

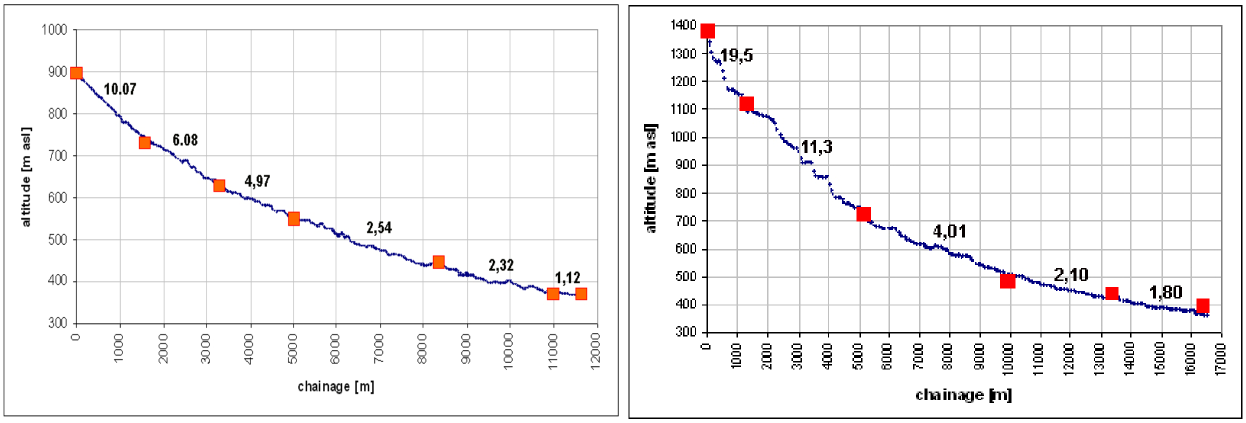

Figure 13. Long profiles of Sushica and Radoviska Reka streambed

a) gorge part (bed load)

b) sedimentation near entering to the city

Figure 14. Sushica basin and stream bed

Because land cover on Sushica basin is very high favorable for erosion processes, almost everywhere is presented pluvial erosion processes. Steep slope in the upper pat of the basin enable transport of the sediment downstream. In the mid pat of the basin stream bad is narrow, water depth in a case of storm event is higher, hydraulic radius is higher and stream velocity is higher. It enables fluvial erosion processes in the stream bed. Depend on the water flow, velocity and energy, sediment including debris is a subject of transport downstream. During storm event , stream velocity in the mid pat where stream bed slope is 3-4%, according to Hjulstrom's Diagram, when steam velocity is higher of 2 m/s, fluvial erosion is enabled and all particles lower then 100 mm are transported downstream. Near the entering to the city streambed expands but slope decrease up to 1,12%, Then depend on the water discharge, steam velocity, hydraulic radius, become aggradations of the sediment in the bed. Although this stream was recognized as dangerous in past, and final design was prepared in 1973, it was only partially implemented. Few cross structures for stabilizing stream bed were built in the urban area near the bridges. Unfortunately a designed check dam hasn't been built and planed biotechnical works hasn't been implemented too. It is a reason for further high erosion processes, smooth transport and deposition of the sediment on the entering to the city.

 

a) fluvial erosion in the streambed b) check dam for retention sediments

Figure 15. Radoviska Reka stream bed

In a case of Radoviska Reka, land cover pattern is not favorable for development of pluvial erosion processes like in Sushica case. But, there are significant number of “open” areas spread on the basin especially in the mid and downer part of the basin where various type of pluvial erosion processes appear. Although bed slope is huge, even 19%, stream bed morphology enable sectioned deposition, because along the stream, there is widening of the stream bed on various sections. One of the very important things is that upstream from the city on the stream bed was constructed a check dam with dimensions: height up to the outflow Hk = 3m, total length L = 24 m. This check dam although constructed 30 yeas ago, hasn’t been fulfilled yet. Than thee is a question for origin of the sediment in the bed in the city. Downstream from this check dam there are few small no-name tributaries seemingly insignificant but erosion processes in 2 of them, steams near the villages Ali Koc and Kodzali, are very strong and it generated a sediment that is deposed in the urban part of the river.

Urban plan and infrastructure

Usually on the transition of the stream from slope area to valley area are located settlements. According to national culture and tradition, people in past located their settlements in this transition part. This geo-position enabled them free area for food production (in the valley) and closeness of the forest for supply of various forest goods (fuel and constructive wood, forest fruits, etc). With enlarging of the settlements and their development, in the beginning, inhabitants constructed their houses or economic units without control, without sense for flood damage. Usually, indigenous people built constructions on the best and lowest dangerous places. Immigrants bought the cheaper or the cheapest land and built their houses. Later detail urban plan solve the problems, but because of poorness of the citizens very often involve former construction in the new plans.

Urban plan and infrastructure in Radoviska Reka vicinity

 

Figure 16. Central pat of Radovis and Radoviska Reka and streets along it

Detail unban plan of the central pat of city of Radovis, where Radoviska Reka pass, is appropriate relate to minimizing flood damages

Along the river there are two streets that enable “open corridor” for flood wave and minimizing damages. According to the final design from 1973, Radoviska Reka was trained with open trapeze shaped channel with dimension a = 20 m, h = 2,05 According to the design, this channel is dimensioned on a 1% peak flow probability, $Q_{1\%}$=152 m^3/s.
The main problem in Radoviska Reka is bridges. 9 bridges pass Radoviska Reka, out of them 7 are irregularly set into the rive bed.

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Figure 17. Irregular bridges close the Radoviska Reka stream bed – Karadacki Bidge

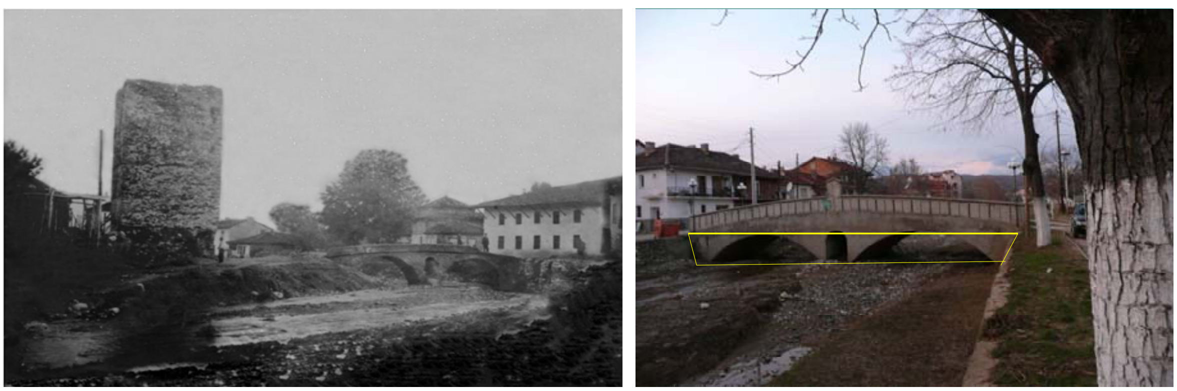

Figure 18. Original Ancient Roman bridge (collapsed 1982) and 2008

According to the measuring and calculation, during the flood event 2008, flow capacity of the streambed near Karadacki Bridge (the first of irregular bridges) was approximately.56 m^3/s. After the flood the bed was cleaned from sediments, then “open area” under the same bridge was measured again, and the calculated flow capacity was Q =84 m^3/s. (instead o f designed 152). It is approximately equal to 10% flow probability. It is so far from standards in Macedonia. Situation with the second bridge (Ancient Oman bridge reconstructed in the 80’s) is worse. Open area of original bridge was something less then 30 m^2 that and it enabled about 110 m^3/s. This bridge was critical in past too, but because of significance as cultural heritage no activities wee carried out related to it. After it collapses in 1982, this bridge was reconstructed. Wishing to build stronger construction, designer enlarges dimensions of the bridge, but it decease open area and flow capacity. Before the flood 2008, flow capacity of this bridge was calculated as Q = 41 m^3/s. After cleaning of the bed, flow capacity increase on about Q = 70 m^3/s that is equal to approximately to 16% peak flow probability.
During the event 2008, streambed near these two bridges couldn’t accept flood water; water poured out from the bed and floods the area along the river in the city of Radovis. More of the sediment was deposed into the stream bed and thee wasn’t large operation fro cleaning of the streets.

Urban plan and infrastructure in Sushica vicinity

Torrent Sushica pass in the new, industrial pat of the city of Radovis. Detail urban plan for this area is prepared but no implemented. Situation and location of the constructions is favorable for increase of damages. Some constructions are much closed to the streambed (figure 20).

Figure 19. A view on Sushica vicinity and devastated area during flood 2008

A problem that contributed to the damages was illegal landfill of constructive solid waste located not so far of the city. Beside other erosive material, large pat of material on the landfill was eroded and transported to the city causing closing of the bridges. The first and oldest bridge was constructed regularly and debits flow easy pass under this bridge. The second bridge (the old enter to the city) was not properly constructed (figure 21). Huge amount of sediment and debris closed the bridge profile and the bridge collapsed (figure 22). Flood wave took each mobile thing including parked truck near the steam. This large amount of sediment and debris closed the third bridge (the newest one). Although according to the witnesses, water “move” the bridge it “survive”. Then the debris flow jumps the bridge and flooded all vicinity of the stream and covered with sediments.

Figure 20a. The second bridge (collapsed 2008),

Figure 20b. The third bridge (closed, 2008)

Impact of Land cover/use changes on erosion, peak flow and flooding - “What – if” scenario

Final question that would be answered is: *What would be changed in erosion intensity, peak flow and flood damages if changes land cover/us pattern on the basins*?

For this purpose was created a following scenario:
- in Sushica basin, to be afforested significant part of the basin and to be built designed check dam;
- in Radoviska Reka, to be afforested bare land downstream from the check dam.

Radoviska Reka scenario:

There are about 700 ha bare land, eroded land II and III category of erosion suitable for afforestation. Total cost of afforestation, according to official pricelist of PE Macedonian Forests) is calculated as over 1 million Euros. .
Related to the erosion processes, land cover pattern is mathematically expressed with Xa – coefficient.
Actual situation is: land cove coefficient Xa = 0,23, erosion coefficient Z= 0,35. If we afforest this area, then land cover coefficient would be deceased Xa = 0,15 and erosion coefficient Z = 0,22. It means about 12% decrease of erosion risk. More significant is that if this measure is carried out, then, significant pat of erosive material production in this area would be minimized and risk of transport of sediment downstream and it aggradations in the streambed in the city would be minimized.
Related to peak flow, land cover pattern is represented with S_2 coefficient. Actual situation is S_2=0,71. $Q_{1\%}$=159 m^3/s. Afforestation of the bare land would decrease the land cove coefficient on S_2 =0,63. Then peak flow would be $Q_{1\%}$= 135 m^3/s or about 15%. This new calculated peak flow is over flow capacity of up mined and analyze bridges Karadacki bridge (84 m^3s) and Ancient Roman bridge (70 m^3/s).
It means that this action would slightly mitigate the flood hazard, but the main problem with irregularly built bridges is not solved.

Sushica scenario:

There are about 1500 ha bare land, eroded land II,III and IV category of erosion, suitable for afforestation. Total cost of afforestation, according to official pricelist of PE Macedonian Forests) is calculated as over 2 million Euros. Cost of designed check dam is cca 150 000 Euros. Total cost of all erosion control woks. Is calculated as 2,15 million Euros.
Related to the erosion processes, land cover pattern is mathematically expressed with Xa – coefficient.
Actual situation is: land cove coefficient Xa = 0,66, erosion coefficient Z= 0,65. If we afforest this area, and built designed check dam, then land cover coefficient would be Xa = 0,16 and erosion coefficient Z = 0,17. It means about 50% decrease of erosion risk. More significant is that if this measure is carried out, then significant pat of erosive material production in this area would be minimized and risk of transport of sediment downstream and it aggradations in the streambed in the city would be minimized.
Related to peak flow, land cover pattern is represented with S_2 coefficient. Actual situation is S_2=0,84. $Q_{1\%}$=58 m^3/s. Afforestation of the bare land would decrease the land cover coefficient on S_2 =0,65. Then peak flow would be $Q_{1\%}$= 44 m^3/s or about 24%.lowe. This new calculated peak flow with elative low quantity of sediment can pass under the bridges on Sushica without problem. Within the bed near the bridges has already built cross hydraulic structures that stabilize the stream bed.
Cost of damages by Sushica only on private property was about 2,3 million Euros. It means that investments in erosion control woks in Sushica basin are lower compared with damages from flood 2008. Because these investments could solve the problem, it is fully recommended to be carried out.

Conclusions

Land use pattern is deep connected with erosion processes and peak flow. Erosion processes and sediment production have a profound effect on peak flow, flood characteristics and damages too.

In a case of Radoviska Reka flooding, land use pattern on the basin influence erosion processes and surface runoff, but it Is not crucial factor for flooding. Even if all bare land would be afforested, erosion intensity would be decrease 12% and peak flow 15%, but it is not enough because irregularly built bridges are the main problem for flooding. Their current flow capacity is decrease on: Karadacki (55% of designed 1% peak flow). And Ancient Roman bridge (46% of designed 1% peak flow). Investments only in land use changes on the basin (afforestation) are not viable.

In a case of Sushica flooding, land use pattern on the basin is the crucial factor that highly influence erosion processes, production of sediment, transport of sediment and deposition, peak flow and flood damages. Land use changes on the basin (mass afforestation of bare land and building check dam) would minimize erosion risk sediment production and transport for 50% and peak flow for 24%. Investments in erosion control works in Sushica basin are lower then flood damages in 2008. It means that this action is high viable and fully recommended for solving the flood problem.

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