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**БРЗА ДИЈАГНОСТИКА КАТАСТРОФАЛНОГ ДОГАЂАЈА КОЈИ СЕ ДОГОДИО 3. АВГУСТА 2015. ГОДИНЕ У ПОЛОШКОЈ ОБЛАСТИ**

**RAPID DIAGNOSTIC OF THE CATASTROPHIC EVENT HAPPENED ON 3RD AUGUST 2015 IN THE POLOG REGION**

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**Abstract:**

Torrent floods bring enormous harm to people and nature, but also can make long-term consequences. These natural hazards origin from the mountains but their consequences are usually felt in downstream sections, particularly in this case, consequences from flood event were felt in the settlements in Tetovo region located on the alluvial fans but in some mountain villages too. Almost all torrents that origin from the Shar Mountain made damages. More of them are dry during the year and there is flow only after heavy rainfalls or snow-melting.

Main objective of this study was to define reasons for this catastrophic event. i.e. reasons for appearance of high debris flow discharge and reasons for damages. Filed observation was done immediately after the event. Terrain was recognized, somewhere in detail. Satellite images done after the event were used too. Beside it, air video material and photoset was used to define some areas. Desktop work was focused mainly on various hydrological analyses.

Heavy rainfall and hail on the Shar Mountain result in huge runoff and discharge. Geological composition (schists and carbonates) and steep slopes, result in huge quantity of sediments even boulder that become part of discharge of this fluid. Sediment was formed as a result of various processes: pluvial and fluvial erosion (formed new gullies, deepened existed gullies, old deposits were eroded that means significant quantity of material was produced and become subject of downstream transport. Beside it, high intensity rainfalls and lateral erosion on the foot of the slopes caused landslides (slow or sudden falling of material into the torrent bed). As a result of weathering, rockfall and talus cone significant quantity of rocky material achieve the torrent bed too. Gravity and huge quantity of water transported all this material downstream in the villages. There were several processes into the stream beds: flowing, traction and rolling of higher particles, even sliding. Depend on the relief characteristics and hydraulic parameters of the stream bed, happened the following physical processes: debris flow, hyper concentrated flow, mud flow even debris slide. The volume of debris by Djepciski Poroj was estimated as 250000 $m^3$ (part of this origin from previous flooding).

An absence of structural measures especially barrages and irregular land use pattern, absence of urban plans, houses along and even into the stream bed, caused enormous damages in the settlements including 6 died, a lot of injured, 24 families evacuated, damages on houses, bridges, roads, infrastructure, on hydraulic structure and on agricultural land. All torrents are assigned as debris flow or debris flood torrents.

**Key words**: torrent, erosion, debris flow

**Апстракт:**

Бујичне поплаве доносе огромну штету људима и природи, али такође могу донети и дугорочне последице. Ове природне опасности формирају се у планинама, али се њихове последице обично осећају у низводним секторима, нарочито у овом случају, последице од поплава осетиле су се у насељима у региону Тетова који леже на алувијалним лепезама, али и у неким планинским селима. Скоро све бујице које потичу са планине Шар направиле су штете. Већина њих су суве током године, а проток постоји само након великих падавина или топљења снега.

Главни циљ ове студије је био да се утврде разлози за овај катастрофални догађај. тј. разлози за појаву наглог и великог протока и разлози за оштећење. Теренско истраживање је извршено одмах након догађаја. Терен је проучен до детаља. Коришћени су и сателитски снимци који су настали након догађаја. Поред тога, коришћени су и видео снимци из ваздуха и сет фотографија за дефинисање погранице подручја. Урађене су разне хидролошке анализе.

Интензивне кише и град на Шар планини узрок су великог отицаја и поплавних таласа. Геолошки састав (шкриљци и карбонати) и стрме падине, резултирају огромном количином седимената чак и већег камења који постају део бујичног тока. Нанос је настао као резултат различитих процеса: плувијалне и флувијалне ерозије (формиране су нове јаруге, продубљене постојеће, старе депоније наноса су еродиране, што значи да је произведена значајна количина материјала која се даље низводно транспортује. Осим тога, падавине високог интензитета и бочна ерозија у подножју падина узроковале су клизишта (спор или нагли пад материјала у зону таложења наноса). Због временског утицаја, одрона и осулинских лепеза (сипара), значајна количина каменог материјала такође стиже у зону таложења наноса. Гравитација и огромна количина воде транспортује сав тај материјал низводно ка селима. Постоји неколико процеса кретања наноса: ток, вуча, ваљање и клизање. У зависности од рељефних карактеристика и хидрауличких параметара воденог тока, десили су се следећи физички процеси: масовни пронос наноса, хипер концентрисани поплавни талас, блатни ток а и клизање наноса. Запремина наноса код Цепчијске Бујице процењен је на 250000 m$^3$ (један део је од претходних поплава).

Одсуство противерозионих објеката у кориту, нарочито преграда и неправилан начин коришћења земљишта у сливу, одсуство урбанистичких планова, изградња кућа поред, па чак, и у водним токовима, изазивали су огромну штету у насељима, укључујући 6 погинулих, много повређених, 24 породице су евакуисане, оштећене су куће, мостови, путеви, инфраструктура, на хидротехничким објектима и на пољопривредном земљишту. Сви водотокови из тог подручј се сврставају у типичне бујичне токове и блатно камене токове

**Кључне речи:** бујичне поплаве, ерозија, пронос наноса

## INTRODUCTION

Mountain regions especially with Alpine configuration are high-risk areas.  Mountain hazards can cause damage, destruction, injury and death at any time and at any place on the slopes or downstream.  Heavy rainfall and hail on the Shar Mountain result in huge runoff and high discharge of the torrents.  But unlike river, significant quantity of sediments even boulder were part of discharge of this fluid. Sediment/debris was formed as a result of various processes. As a result of pluvial (rainfall) erosion and fluvial erosion (erosion by water discharge into the stream) were formed new gullies, existed gullies were deepened and widened, old deposits were eroded that means that significant quantity of material was produced and become subject of downstream transport. Beside it, high intensity rainfalls and lateral erosion on the foot of the slopes caused landslides (slow or sudden falling of material into the torrent bed). As a result of weathering, rockfall and talus cone significant quantity of rocky material achieve the torrent bed too. Gravity and huge quantity of water transported all this material downstream. More than 10 torrents caused damages. All these streams including river Pena origin from the Shar Mountain and are typical mountain stream with torrential character. More of them are dry during the year and there is flow only after heavy rainfalls or snow-melting. The consequences of the event were: 6 dead, 11 injured, 24 families evacuated in Šipkovica village, Power cut off in several villages, damaged water supply system (Tetovo, Šipkovica...), damaged houses, 11 damaged bridges, 17 damaged roads, damaged hydraulic structures into the torrents bed, damages in the stream bed, affected agricultural land: 40 ha etc. Total costs of damages was estimate as 25 000 000 Euros.

**THEORETICAL BACKGROUD**

Torrent floods bring enormous harm to people and nature, but also can make long-term consequences and usually return development a few years back. These natural hazards origin from the mountainous regions but their consequences are usually felt in downstream sections, particularly in our case, consequences from flood event were felt in the settlements in Tetovo region. Level of destruction of the natural disasters damages depend on the natural but also depend on socio-economic conditions.

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. 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. 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 (http://earthsci.org/flooding/unit3/u3-03-04.html).

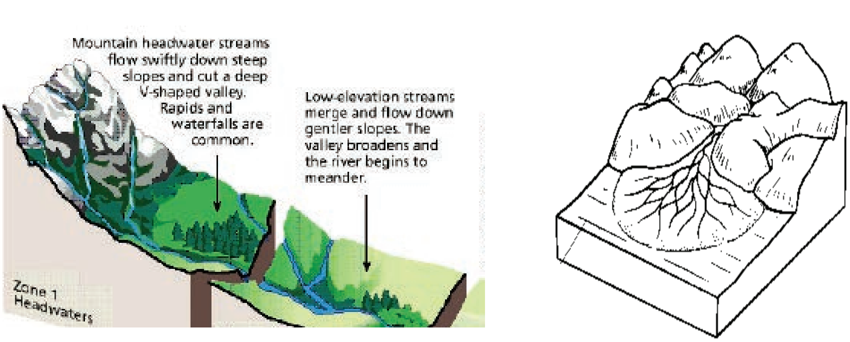



**Figure 1.** Torrent morphology

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 river will generally decrease creating a concave long profile with distance downstream and deposition serves 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 river 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 time 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 (http://coolgeography.co.uk/A-evel/AQA/Year%2012/Rivers,%20Floods/Long%20profile/Long%20profiles.htm).

Natural geomorphologic processes influence stream basin fluxes to varying degrees. Peak of Discharge depends on various factors: rock and soil type; land use; rainfall intensity; relief characteristics; weather conditions before and during the event; conditions of soil before and during the event. ·Factors causing Erosion are: climatic factors, vegetation cover, soil characteristics, relief and human activities. Factors causing Landslides are: climatic, geological, morphological, relief conditions and human activities.

On the other hand damages depend on the human activities especially land use. 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. 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. http://floods.jrc.ec.europa.eu/land-use-modeling-and-natural-hazards.html

Debris flows have volumetric sediment concentrations exceeding about 40 to 50%, and the remainder of a flow's volume consists of water. By definition, "debris" includes sediment grains with diverse shapes and sizes, commonly ranging from microscopic clay particles to great boulders. Debris flows are accelerated downhill by gravity and tend to follow steep mountain channels that debouche onto alluvial fans or floodplains. The front or 'head' of a debris-flow surge often contains an abundance of coarse material such as boulders and logs that impart a great deal of friction.

The debris mainly comprises large boulders, rock fragments, gravel- to clay-sized material, tree and wood mulch – materials that accumulate in the mountain creeks. To be susceptible to a debris torrent, a creek must have a drainage area within a critical range, a profile that is sufficiently steep, an accumulation of debris, and some form of triggering mechanism. The most common triggering mechanism is an extreme water discharge, which may result from a very intense rainfall or a temporary damming of the creek. (D. F. VanDine, 1985)

According to Johnson (1970) debris flows, whether channelized or unchannelized, are rapid flows of unsorted debris that normally show visco-plastic or dilatant rheology or some combination of These. Debris torrents, by contrast, show a combination of dilatant and uniformly dispersed grain flows (Takahashi, 1981). Eisbacher (1982) pointed out that Europeans use the term "torrent" (a translation of "*wildbach*" according to Eisbacher, Aulitzky's translator, and an obvious equivalent of the French ***"torrent"*** and Italian ***"torrente")*** to refer to a mountain stream. (ex-cited by Slaymaker O. 1988)

## AIMS AND OBJECTIVES

The aim of this study was to be done rapid diagnose of the catastrophic event happened on 3rd August 2015 in Tetovo region

The basic questions were:
- What were the reasons for hazard?
- What was the reason for huge damages?
- What type of torrential event happened?

## METHODOLOGY

The prime activities were preliminary desktop analysis: collecting all necessary available maps, collection all necessary data, measuring of the basic parameters of the torrent catchments.

During the field work were spent several days not only in the affected settlements but on the catchments too. Some measuring of some necessary parameters was done (slopes, bed dimensions…) were taken pictures and clips. Significant data about the event was collected through interviewees with people from the affected region.

After the field work various analysis were done.  Data was transmitted on the maps, were used maps produced by Copernicus SRM. Analysis of literature data especially historical data about the past events was done. All these analyses were done to be answered the first two questions.

For the definition of torrent type was used Aulitzky classification. Aulitzky (1980) suggested two-fold classification.

| | |
|---|---|
| 1. | Classification according to the extreme catastrophic behavior on the debris cone (debris fan, lower course, redepositional reach or on another point of the basin) |
| 1.1. | Debris flow torrents – They characterised by non-Newtonian viscous, gravitational flows with pulsating and blocking debris discharge reaching velocities up to 30 ms"1. |
| 1.2. | Debris flood torrents – They are subject to viscous mass flows without pulsating and blocking debris flows. They have lower velocities and less transporting power than debris flow torrents. |
| 1.3. | Bedload transport – They have little fine-grained sediment so that gradient and depth of flowing water control tractive forces as in standard hydraulic situations. |
| 1.4. | Flood Creeks - They carry largely fine-grained sediment, and are of no direct relevance to the topic of debris torrents. |
| 2. | Genetic classification related to the type of erosion processes in the catchment basin |
| 2.1. | Torrents with erosion from surface erosion |
| 2.1.1. | Torrents with depth erosion (scour torrents) |
| 2.1.1.1. | Natural scour torrents (Colluvial, Volcanic, Bedload, Partial, torrents with strong infiltration, Gullies, Debris accumulating torrents) |
| 2.1.1.2. | Induced scour torrents |
| 2.1.2. | Lateral erosion torrents |
| 2.1.2.1. | Natural lateral erosion torrents (torrents with predetermined channel bend, torrents with free meanders, grass-scare torrents) |
| 2.2. | Torrents with embankment failures |
| 2.3. | Special torrents (ice debris flow, snow debris flow, karst, glacial or earthquake torrents) |

## STUDY REGION CHARACTERISTICS

Affected area belongs to the Polog Region that consist of Polog valley and mountains from east (Suva Gorsa) and west (Shar Mountain). Šar Planina (Shar Mountain) is located in the northwest part of the Republic of Macedonia. It is one of the highest (top Turcin, 2.748 m) and the biggest mountains ($A = 840.2$ km$^2$) in the Balkan.

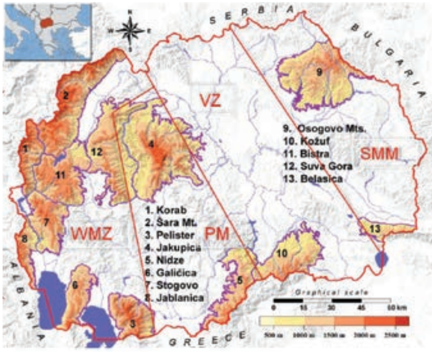



**Figure 2.** Mountains higher than 2000m (Milevski, 2015)


**Figure 3.** Shar Mountain and Polog Valley

Shar Mountain belongs to Western Macedonia geotectonic zone. On a global scale in shaping the area of the mountain range Shar (and beyond) as influenced Variscan and Alpine orogeny. Territory of the Shar Planina is divided in 3 sections (End segment of the southern mountains, Central section (with south and north) and Extreme northeastern segment.

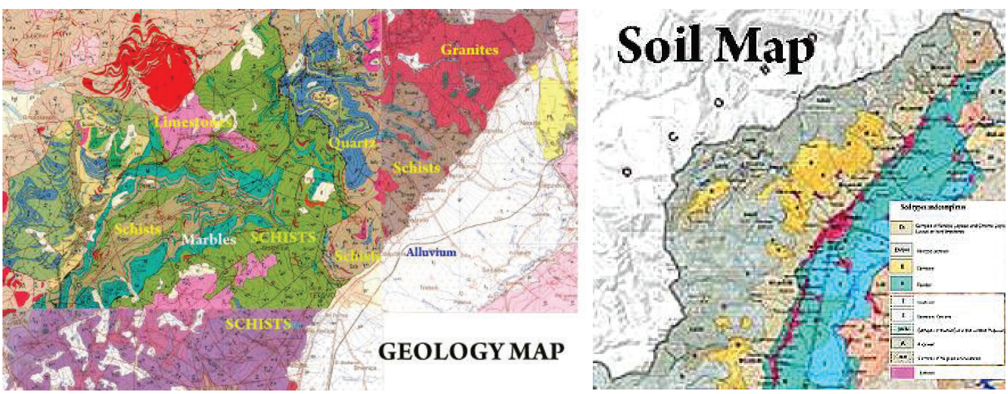



**Figure 4.** Geology and Soil Maps of the region

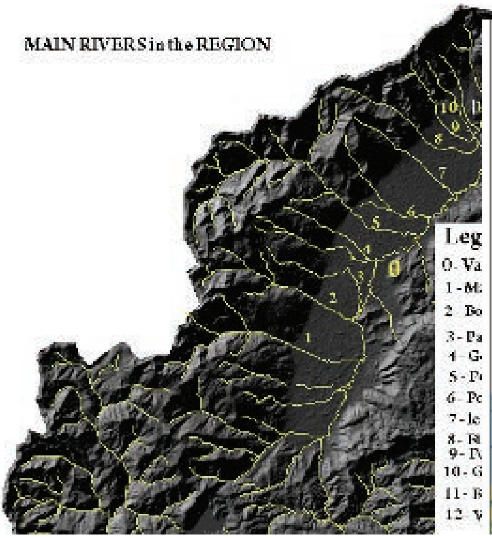
The **southern segment** covers the area north of Valley River Mazdracha to Nichpurska Mountain to the south. Here is dominated by Paleozoic phyllites and Paleozoic metasandstones and less meet and quartzite of the same age. This part was not affected by catatsrophy in this event. In the **middle part of Shar Mountain**, i.e. in southern central segment (south of the river valley of Pena) represented a number of lythofacial formations. More significantly present series of green schists and diabases. Significant is presence of Paleozoic schists and phyllites which are mainly encountered along the middle and upper River Valley Pena. In the higher parts of the right side of the valley Pena (from top to Ceripashina Turcin) there are Triassic crystal limestones. On the ridge Kara Nicholas and the right valley side of River Pena Paleozoic marbles are presented. In the northern part of the central segment, north of the Pena Valley up to the valley of the Bistrica River dominated old Paleozoic and Paleozoic shale, Significant is presence of quartz sandstones and quartzite, in the southeast of Black Peak (2.585 m) to the Kuchi Baba (2.209 m). In this section, in the lower parts of the mountain, the more locations of old Paleozoic e schists are disrupted by Paleozoic granites. **In northern Shar Mountain** (northeastern segment), i.e. from Bistrica River valley up to the peak Ljuboten (2.499 m) dominated 3 lythofacial formations (Paleozoic granites, old paleozoic schists, are Triassic marbleized limestones. (*Source: Geology Map of RM*)

**Soil** structure consists of various soil types depend previously on parent rock as well as other pedofactors. On the highest altitudes on a silicate parent rock (schists) are developed rankers. On the same altitude but on calcareous parent material is developed calcomelanosol. It is shallow soil too and pedogenesis is over 1000 years. Leptosols (Lithosols) are very shallow soils over hard rock or highly calcareous material, but also deeper soils that are extremely gravelly and/or stony. Cambisols are characterized by the absence of a layer of accumulated clay, humus, soluble salts, or iron and aluminum oxides. They occupy significant area dominantly covered with oak and beech forests. Fragmentary appears regosols and rendzinas too. In the lower part of area are developed fluvisols (colluvial and alluvial soils) and urbisols (in the settled area). Sandy loam soils cover almost all mountain regions. Soil types and texture classes are very important for vegetation cover and for runoff and erosion vulnerability too (*Source – Soil Map of RM).*

**Climate** in Tetovo is assigned as sub-humid Climate on Popova Shapka is per-humid and the total annual sum of precipitations is slight below 1000 mm. Maximal daily precipitations in Popova Shapka were registered in November 1979 {188 mm) and few-days precipitations caused huge flooding of Tetovo (by river Pena) as well Skopje (by river Vardar).

The **water treasure** of Shar Mountain, consist of large number of springs, more glacial lakes and steep mountain streams. Over 100 springs of Shar Mountain occur in the bases of talus cones, then the bases of the rocky sections, bare and grassy slopes etc. From Shar Mountain to Polog Valley run down over a hundred, minor or major waterways. Springs of the most rivers are on altitude over 2.400 m. In the most upstream part, they are composed of a network of smaller streams. All rivers in the Shar Mountains belong to the catchment area of the river Vardar, and most of them are its direct tributaries. All of them have torrential character.

**Slopes** of the Stream beds are generally over 30% in the mountain part, partially over 50% (Poroj – Brza Voda). Mean catchment slopes are very steep too. Typically for all streams is their torrential character. Mean erosion coefficient in the country is 0,31 while in Shar Mountain region is 0,54. The most erosive catchment in the region is Poroj (Z = 0,75). In RM 36,5% of the territory belong to I-III category of erosion, while in the Shar Mountain region 77%.



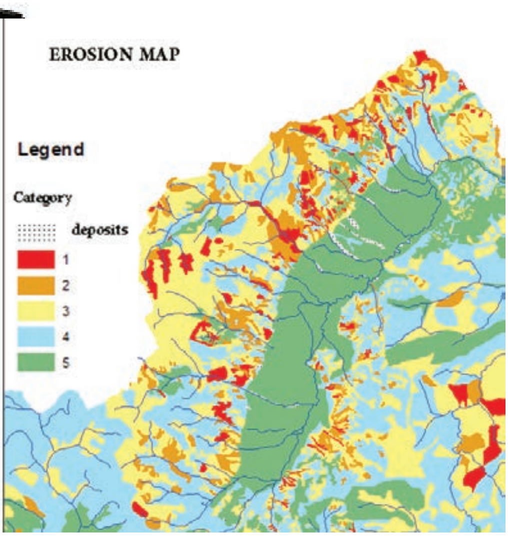




**Figure 5.** Main torrents

**Figure 6.** Erosion map (Gorgevic et al, 1993)

**Table 1.** Main hydrological parameters, erosion and sediments

| No | Torrent Name | Catchment area | Torrent length | Catchment perimetere | Catchment slope | Erosion coefficient | Par of area I and II cat. | Total produced sediments | retention coeff | Total transp. sediments | Spec. prod. sediments | Spec. trans. sediments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A km² | L km | O km | J % | Z | $Z_{1,2}$ % | W m³ | Rn | G m³ | Wsp m³/km² | Gsp m³/km² |
| 1 | Mazdraca | 89,0 | 26,4 | 64,2 | | 0,43 | 9,9 | 68595 | 0,91 | 62421 | 795 | 723 |
| 2 | Bogovinska Reka | 61,4 | 20,5 | 36,6 | 43 | 0,62 | 23,8 | 80872 | 0,91 | 73594 | 1317 | 1198 |
| 3 | Palcishka Reka | 23,3 | 11,8 | 24,9 | 40 | 0,44 | 12,1 | 19870 | 0,88 | 17486 | 852 | 750 |
| 4 | Golema Rechica | 13,6 | 9,5 | 19,5 | 39 | 0,48 | 8,2 | 12690 | 0,92 | 11675 | 934 | 859 |
| 4a | Poroj Mala Recica | 2,7 | 5,7 | 11,5 | 41 | 0,50 | 36,8 | 2860 | 0,69 | 1973 | 1051 | 725 |
| 5 | Pena | 191,6 | 40,0 | 82,0 | 50 | 0,57 | 21,6 | 230800 | 0,78 | 180024 | 1205 | 940 |
| 6 | Poroj | 16,2 | 9,7 | 19,2 | 46 | 0,75 | 58,3 | 30784 | 0,85 | 26136 | 1904 | 1618 |
| 6a | Neproshtenska | 5,9 | 5,4 | 11,8 | 40 | 0,49 | 25,3 | 5922 | 0,81 | 4797 | 1004 | 813 |
| 7 | Leshochka Reka | 14,2 | 15,2 | 33,5 | 56 | 0,52 | 30,3 | 15182 | 0,94 | 14271 | 1069 | 1005 |
| 8 | Bisrica | 37,2 | 21,1 | 44,5 | 61 | 0,58 | 40,5 | 45888 | 0,93 | 42676 | 1233 | 1147 |
| 9 | Ponika | 4,6 | 4,1 | 9,6 | 50 | 0,47 | 26,0 | 4504 | 0,65 | 2928 | 975 | 634 |
| 10 | Gabrovnica | 16,5 | 14,0 | 29,0 | 59 | 0,62 | 39,7 | 21735 | 0,90 | 19561 | 1317 | 1185 |
| 11 | Belovishka Reka | 11,8 | 13,0 | 28,5 | 60 | 0,49 | 21,6 | 11003 | 0,85 | 9353 | 932 | 793 |
| 12 | Vratnichka Reka | 30,5 | 13,5 | 31,0 | | 0,91 | 24,6 | 31625 | 0,98 | 30992 | 1036 | 1016 |
| Mean value for the region | | | | | | | | | | | **1127** | **964** |
| *Mean value R Macedonia* | | | | | | | | | | | ***680*** | ***303*** |

In the mountain area dominate grasslands used for sheep grazing. Taking in consideration slopes of the terrain, relief dissection, shallow soils and land cover, run off in this area is huge. Beside it, in this zone appeared bare lands (dominantly rocky notches/cliffs) that are prone to weathering. This entire high mountain zone generates significant part of the discharge and quantity of sediment material. Below this zone are spread forests (dominantly beech forest). In this zone soil is highly protected by pluvial erosion. Soil structure is good and combination of soil and coverness enable high acceptance of rainfalls. On the other hand into the forest appear gullies that are not visible form space.

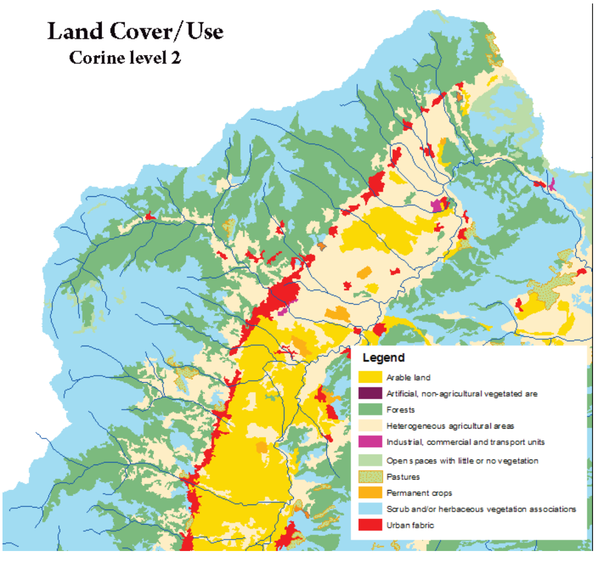



**Figure 7.** Land Cover/Use map

There are open spaces in the forest zone classified as heterogenous agricultural area. Within this area dominate grasslands used for sheep grazing. These areas contribute to high discharge and erosion processes. There is private and state property. State owned pastures under competences of Public Enterprize "Macedonian Pastures". Forests in state property are managed by state public Enterprize "Macedonian Forests" – regional office "Leshnica" – Tetovo. Forest is managed according to the forest management plans. Forest in private property are managed by their owners but they carry out forest activities based on a permission by private forest engineers (in previous years) and engineers from state owned enterprise. Forest activity (cut, logging, transport) without permission is punishable according to the Criminal code. Preliminary comparison of satellite images from various period (2002 - 2014) doesn't show any significant **land cover changes** in the most affected catchments (Shipkovica, Recica, Poroj) that have significant influence on the hydrological regime. Only in depth Remote Sensing analyzes can get the right answer.

## DESCRIPTION OF PROCESSES

### <u>Climatologically situation before and during the event</u>

July 2015 characterize with long dry period without precipitations and very high temperature that in the lower parts achieve over 35$^{o}$C. This climatic situation influenced the soil structure. Soil was dry, materials that improve soil structures evaporated and soil particles became incoherent. It means that rainfalls easily can displace soil particles. The most upstream parts of the torrent catchments are located on the shallow soils and covered with grasslands.

On the critical day 3rd August, happened storm over the highland on the Shar Mountain. Air mass traveled from the Adriatic Sea, cooled and condensed on the mountain and storm event occupied this area. Precipitation station in Tetovo in the valley registered only 9 mm. On the other hand station located in Jazince (north from Tetovo) registered 50 mm for 24 hours. According to the local people (shepherds) storm duration on the mountain was 2 hours, firstly no intensity rainfalls and then high intensity rainfalls. Probably duration of the high intensity rainfalls was between 60-90 minutes. If we accept intensity of 1 mm/min total rainfalls would be between 60-90 mm On the other hand using pluviometric gradient (1mm/30 m) then Jazinnce is located on 900 masl, on the mountatin 2000 masl. Altitude difference is 1100 m or 36 mm. Then 50+36 = 86 mm rainfalls on the mountain. Without exact data because Popova Shapka station was out of use as well as the new automatic stations hasn't operate yet, and the radar was shut of (to avoid electric shocks because of storm event) this is only assumption and is uncertain.

**Description of processes in the torrent beds**

Taking in consideration catchment areas, length and slopes and land cover especially in the upper parts, time for concentration is so short. IN the upper part of the catchments was created the flood wave. Grassland on very shallow soil couldn't retent the water. Excluding river Pena, other scenarioc are very similar. Huge water discharge formed in the upper part cause strong fluvial erosion processes, deepening of the beds and lateral erosion. This lateral erosion process cause landfalls, landslides, rock falling i.e huge quantity of solid material into the beds. All this fluid travel downstream, somewhere the biggest boulders stop, but somewhere boulders achieve even the foot of the slopes.

**Figure 8.** Fluvial erosion processes and landfall into the bed (Shipkovica central, Shipkovica 3, Recica)

Absence of cross structures - barrages and steep slope as well as bed shape enable free way for this fluid downstream. The most quantity of sediment was deposit from the Poroj stream.

**<u>What's happened in different torrents?</u>** All text in this chapter - Blinkov I., 2015

***Torrent Poroj***

This torrent permanent attack mainly the road Tetovo-Jazince and the bridge. Several times in the recent history Poroj did huge damages. The first time was trained in the 30's after huge flood. Later were constructed classical stone check-dams that were destroyed ion flood in 1979. After that were constructed 4 screw check-dams - Herheuldize type. Taking in consideration that these dams were constructed on –field, they were destroyed later when a great boulder of cca 25 m$^3$ broke them. There was a massive gravitorial check-dam upstream from the screw-dams.

**Figure 9.** Poroj Catchment, flooded area by torrent and deposits

The width of flooded area along the road was 800 m. Significant quantity of sediments were deposed near the bridge and width of this area was 150 m and length 200, (upstream and downstream form the bridge). In the provisional critical zone there is only 1 facility (petrol station) and the pavement was flooded and depth of sediment achieved 0,5 m. Taking in consideration [past events, houses in the village of Poroj are so far of the critical zone. Great part of the catchment area is covered with grasslands where soil is shallow. Even in the mid part around the village of Germo dominate cultural landscape. Slope inclination is extreme steep. Erosion intensity is so high, the highest in the region and one of the highest erosion intensity of any torrent area in Macedonia. Beside it, there are rock-falls, weathering, landslides, stream bank erosion is huge, It generate huge quantities of sediment. The torrent Poroj has on average a moderated steepness however, at one point, it reaches a maximum level of 47.7%, which is to be considered as high (name Brza voda – fast water). For that reason this torrent has huge transport capacity. Transported huge amount of sediment leaving large amounts (sand, sediment, rocks etc.). Huge quantities of sediments are not stopped behind ruined check dams and deposit sediments when the torrent bed slope radically decrease. Bridge on the road Tetovo – Jazince contribute to the flooding too. Landslide in Germo is different problem but contribute to torrential floods.

***Torrent Shipkovica 3***

Origin form the high mountain region. Very small and narrow torrent but very dangerous. Long profile of this torrent is specific and enable deposition of sediment in certain areas. One of this areas is just above the road Shipkovica – Brodec. Characterize is extremely big boulders some of them with volume > 15 m$^3$.

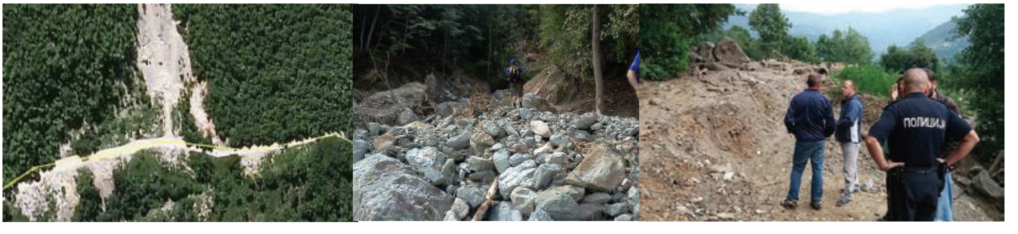



**Figure 10.** Shipkovica torrent 3 - Sediment area, boulders 2015 and damaged road 2016

***Torrent Shipkovica - central torrent***

This torrent cause huge damages and 4 died citizens. Catchment area of the torrent is small (1,5 – 2 km$^2$). As a result of rainfalls and huge runoff on grasslands, a flood wave was created.


**Figure 11.** Shipkovica central torrent- catchment area- Collapsed dam (1) and sinkhole (2)

In past, after the flood in the 1932 dam were constructed on location 1 and channel to the sinkhole (assigned as lake on the map). With these interventions a catchment area was amputee and decrease on 1/3. Water flowed to the sinkhole and infiltrated in the ground. During the event on 3rd August, a dam collapsed and the flood wave continues to Shipkovica. Part of the debris was deposed near the location 2 where torrent bed changes the slope and width. From the section between location 3 and 4 are the highest processes and the biggest sources of sediment.

The last 350 m above the Šipkovica (section 3-4 on the map) the deep erosion processes produced providing the material for the damages in Šipkovica itself. The slope angle ranges between 30 to 40° to NE. On the both sides of the gully which has depth up to 20 m is visible only soil (weathered bedrock). It seems that the gully eroded in to former debris flow deposits. The largest boulders have a diameter up to 7m.

When torrent enters in the village the first problem was no.2 (very narrow channel). House nr.1 was barrier and started deposition before it. The huge power of water demolishes the walls on 2 rooms of the house (1) and passed away. After that the flood wave demolishes the back wall of the side room in the house no.3 and outflow through the door and window. There was 1 died in this house. After the outflow from the narrow channel there were additional problem – an arch wall (no.4) and parked car and farm house. Then water change direction and together with water that pass through house no.3, hit the houses near house no.5. They were barriers and deposition started even into the houses. The first floor of the house no. 5 was fully fulfilled with debris. There were 3 died in this house. Rest of the debris continue to the main street where deposed huge quantity of sediments.


**Figure 12.** Location of structures along the torrent

***Torrents Golema Recica and Mala Recica***

High altitude difference (1500m), high bed slope (>25% even partially >50%), low coverness and soil, contribute to huge peak of discharge. Erosion process in the catchment contributes to creation of significant quantity of sediment that cause torrential flood in the village of Golema Rečica. There are a lot of structures located in possible vulnerable zone to flooding. Bigger particles of the sediment even boulders were deposed in the part before the begging of the channel.

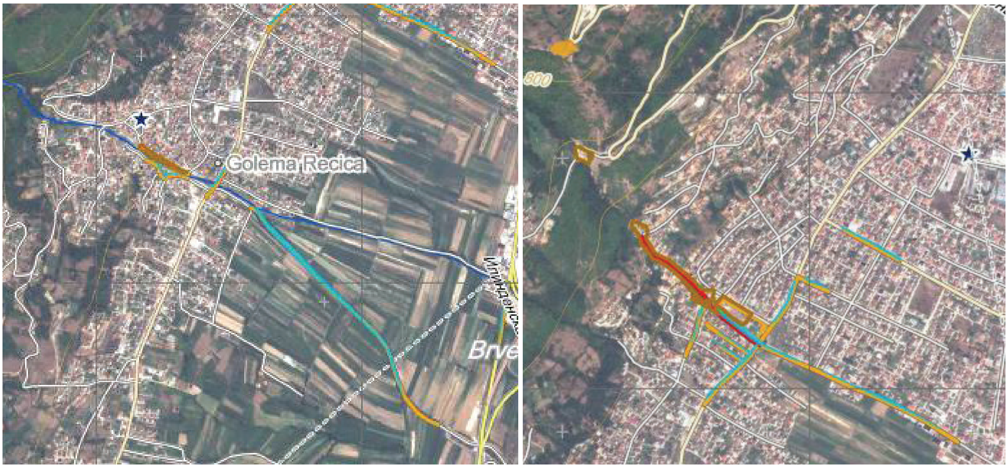



**Figure 13.** Delineated flooded area in Golema and Mala Recica (Source: *Copernicus EMS*)

Due to the vicinity of settlements, catchment area of Mala Rečica characterize with a low forest cover (on the left side probably overexploited in past) and a significant grassland area. Beside it denudation processes on the slopes and deep erosion processes together with weathering are reason for generation of big particles of sediment (visible on the right photo). There aren't cross structures into the torrent bed in this area. Beside the road to Rasadishte, are illegal landfills of various constructive wastes. There is a constructive waste. In the same area happened landslide. All this material through the torrent bed was transported to the village Mala Rečica. It was combination of mud flow and debris flow. Bigger particles were deposed in the upper part and then mudflow deposed significant material in the other part.

***River Pena***

The river of Pena is the biggest tributary to Vardar formed on Shar Mountain. Catchment area of Pena is 191 $km^2$. It has the longest mountain watercourse with 29,7 km from the source to Tetovo. Its altitudinal difference is 1.914 m. Catchment shape, catchment area and slopes contribute to appearance of coincidence of discharge form 2 parts near Brodec and huge quantity of water and energy. The most erosive part is located 12-13 km upstream from the mouth. Into the river bed there is a lot of sediment and boulders result of various processes in the tributaries and the direct streambank as weathering, landfalls, rockfalls, streambed erosion etc. Six screw-dams upstream from Tetovo are functional although some of them are significantly damaged. During the storm event (strong wind), a lot of debris (woody, plastic even mineral from street runoff) achieve river bed of Pena and together with material that Pena transported from upstream part blocked the bridges in the city of Tetovo. Definitely, there were past sediments deposed in the river bed that decrease the profile of the river bed. Bridges were blocked by debris, create backwater and out flowing of river Pena that cause flooding of parts of the Tetovo city.


**Figure 14.** Pena river catchment, weathering and critical areas in the city (bridges)

Beside up mined additionally few torrents cause damages too as follow: Neprostenska Reka, Ponika, and some tributaries of Pena River.

**Other reasons for huge damages**

There are a several reasons for this starting with land use. People awareness is very low and some human activities contribute to the damages as position of settlements, wild landfill with constructive waste located near the torrent bed (example in Rečica and in Shipkovica) and inappropriate building.

Almost all settlements are located on the alluvial fan of the torrents. An absence of urban plans in the villages causes urbanistic chaos. Typical example is Shipkovica where some houses were rebuilt even in the torrent bed. The same situation was in Rečica bed. Only citizens of the village of Poroj ("poroj" means torrent) faced with permanent flooding in the past, know the hazardous area and don't built any construction in this area.

Legal and Intuitional setup is no suitable for this type of event, because of low awareness of torrent hazards of the institutions, local or national both. Almost nobody in the institutions even on national level understands difference between river and torrent. It cause application of river training method for the torrent control i.e. uneducated people for torrent control prepare designs.  Except in Pena, there are no barrages in other torrent beds. It results in transport of huge quantity of sediment even big rocks to the settlements.

## What kind of event happened?

This characterization and classification was done according to the Aulitzky classification. Out of all torrents in this study will be defined only the following: Rečica, Poroj, and Shipkovica. River Pena is trained with cross structures and because of that is evaluated in the current situation.

**Table 2.** Type of torrents according to Aulitzky classification

| | I criteria – hazard along the cone, fan, | | | | II criteria – Generic classification regarding erosion processes | | |
|---|---|---|---|---|---|---|---|
| **Name** | **Bed Slopes %** | **Debris/ Sediments** | **Viscosity** | **Final classification** | **Surface erosion scour** | **Surface erosion lateral** | **Embankment failure** |
| Shipkovica torrents | 23 | Up to big boulders | Non-Newtonian | Debris flow torrent | yes | yes | yes |
| Poroj | 22 | Up to big boulders | Non-Newtonian | Debris flow torrent | yes | yes | yes |
| Golema Recica | 21 | Up to big rocks | various | Debris flow/ Debris flood torrent | yes | yes | yes |
| Mala Recica | 22 | Up to big rocks | various | Debris flow/ Debris flood torrent | yes | yes | yes |
| Pena (with barrages) | 16 | Fine clay to rocks | Newtonian viscous mass | Debris flood/ torrential river | yes | yes | yes |

**Table 3.** Torrent index

| | **Shipkovica torrents** | **Poroj** | **Golema Recica** | **Mala Recica** | **Pena** |
|---|---|---|---|---|---|
| Maximum grain volume of recent eroded material | >1 m$^3$ 4 points | >1 m$^3$ 4 points | >1 m$^3$ 4 points | >1 m$^3$ 4 points | 0,01-0,2m$^3$ 2 points |
| Maximal thickness of the debris layer | >1m 4 p. | >1m 4 p. | 0.5-1m 3 p. | 0.5-1m 3 p. | 0.5-1m 3 p. |
| Inclination of the debris cone domain under study* | >15% 4 p. | >15% 4 p. | 2-7% 2 p. | 2-7% 2 p. | <2% 1 p. |
| Present vegetation cover on the basin | Meadows up, birch bellow 2,5 p | Meadows up, birch bellow 2,5 p | Meadows up, birch bellow 2,5 p | Meadows up, birch bellow 2,5 p | Meadows up, birch bellow 2,5 p |
| Are the erosional features and surface irregularities on the debris cone domain | Debris ridges and features with coarse blocks – 4p. | Debris ridges and features with coarse blocks – 4p. | Poorly defined depositional features 3 p. | Poorly defined depositional features 3 p. | Poorly defined depositional features 3 p. |
| The discharge situation on debris cone is | Blocking structures that inhibit flow - 4p. | With blocking structures that inhibit flow - 4p. | With blocking structures that inhibit flow - 4p. | With blocking structures that inhibit flow – 4p. | With blocking structures that inhibit flow – 4p. |
| Total points | 22,5 | 22,5 | 18.5 | 18.5 | 15.5 |
| **Torrent index** | **3.75** | **3.75** | **3.09** | **3.09** | **2.58** |
| **Description** | Most endangered | Most endangered | Most endangered | Most endangered | Most endangered |

**Table 4.** Characterization of the torrent type

| | **Shipkovica torrents** | **Poroj** | **Golema Recica** | **Mala Recica** | **Pena** |
|---|---|---|---|---|---|
| Debris flow and flood have in the past | Caused considerable devastation in the old community – 4p | Caused considerable devastation in the old community – 4p | Cause devastation of newly buildings along the torrent - 2p | Cause devastation of newly buildings along the torrent - 2p | Caused considerable devastation in the old community – 4p |
| Potential maximum one-day precipitations | 100-150 mm 2 p. | 100-150 mm 2 p. | 100-150 mm 2 p. | 100-150 mm 2 p. | 100-150 mm 2 p. |
| Location an potential debris volume in the upper part of the catchment | Large debris source separated by open gorge channel – 3p | Large debris source separated by open gorge channel – 3p | Closes debris source separated by flat torrent reach - 2p. | Closes debris source separated by flat torrent reach - 2p. | Closes debris source separated by flat torrent reach - 2p. |
| Role of unrooted trees or logs in debris flow/flood | Single trees and swamps reach torrent - 3 p | Single trees and swamps reach torrent - 3 p | Single trees and swamps reach torrent - 3 p | Single trees and swamps reach torrent - 3 p | Only branches can reach torrent bed – 1p |
| Water storage potential of the bedrock and surficial material | Inclined shale-marl units 2 p. | Inclined shale-marl units 2 p. | Inclined shale-marl units 2 p. | Inclined shale-marl units 2 p. | Inclined shale-marl units 2 p. |
| Total points | 14 | 14 | 11 | 11 | 11 |
| **Torrent index** | **2.8** | **2.8** | **2.2** | **2.2** | **2.2** |
| **Description** | **Torrent with potential for debris flow** | **Torrent with potential for debris flow** | **Potential for bedload transport** | **Potential for bedload transport** | **Creek with flood potential** |

In the above text was mentioned that more of the experts doesn't make difference between big river flood control and torrent control. In the village of Rečica there is a channel in the urban area designed using only water flow discharge although there is no any cross structures for sediment retention in the upstream part. Even in a feasibility study for flood control in the Polog region (2015) for future designing are recommended water flow discharge values (calculated using hydrological models for flow discharges) assigned as "minimal prevail discharge". For example: for Poroj – 15 m$^3$/s, Rečica – 10 m$^3$/s.

Crucial problem is that for designing torrent control designs only civil construction engineer (not only hydraulic engineer but also other) can got permit by the Chamber of engineers. Forestry engineers' even specialists for erosion and torrent control can not apply for this type of permission although the only faculties where this disciplines (Erosion and Torrent control and additional related to courses) are in the study programme on the Faculty of Forestry.

Using different hydrological models Panov (Flow2d) and Stojov (HEC) calculate the same value for the discharge during the event in Shipkovica – 15 m$^3$/s. During the event in Shipkovica there were discharge in the narrow "channel" 1,2 (width) x 4,5 m (maximal height based on traces on the wall) i.e. A = 5,3 m$^2$. Due to absence of video material in the critical area and critical time, was tried to define velocity of the flood wave showing to the witnesses the video material from various torrential floods. It is very uncertain to define the velocity taking in consideration psychological condition of the people that show faster torrents, was assumed that minimum velocity was 5 m/s although theoretically by various authors could rich 30 m/s and more In this case discharge only in the channel was at least 25 m/s. In the same time flood wave cannot pass through the "channel" and ruined 3 walls in 2 houses (figure 12) and exit through the door and windows. If we added this discharge was much higher than using classical hydrological models for water flow discharge.

Definitely, the debris flow discharge differs from water flow discharge. The debris-flow discharge is an important variable when designing debris-flow mitigation structures such as culverts, flumes, bridges, debris-flow barriers, and check dams. It is very complicate to define the debris flow discharge. There are various methods. A variety of empirical equations relating the debris-flow peak discharge to the debris-flow volume (Mizuyama et al., 1992; Jitousono et al., 1996; Rickenmann, 1999) and the debris-flow peak discharge to the watershed characteristics (Bovis and Jakob, 1999) have been proposed to estimate the discharge. Attempts have been made to correlate the water-flow discharge Qwp with the debris-flow discharge Qdp (Takahashi, 1991; VanDine, 1985; Chen et al., 2008). The relationship between Qdp and Qwp was widely used in engineering planning because Qwp,which is related to the return period, can be easily determined by hydrologic analysis. The assumed Qdp is proportional to Qwp and is expressed as Qdp = cbQwp, where cb is the discharge coefficient of the debris flow (**J.-C. Chen and M.-R. Chuang, 2014**).

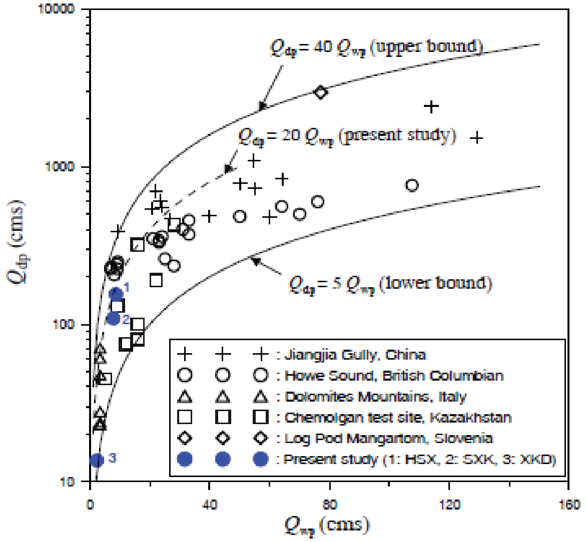



**Figure 15.** Relationship between the debris-flow discharge Qdp and the water-flow discharge Qwp (J.-C. Chen and M.-R. Chuang, 2014).

Above figure show that Debris flow discharge is 5-40 times higher than the water flow discharge. It additionally proves mistakes in torrent control designing in Macedonia in the last 15 years. Taking in consideration complexity of this issues it would be studied in further research.

## CONCLUSION

On the critical day huge quantity of precipitations above 80 mm fall in a short period 2,5 – 3 hours. Taking in consideration all natural and socioeconomic factors, Shar Mountain region is highly prone to erosion processes. Taking in consideration geological structure, slopes and other factors, significant number of landslides and rockfalls exist in the area. In a sense of erosion and flooding, landslides and rockfalls whose appearance in the region is significant are accepted as a great source of sediment that cause further damages in the downstream sections of the streams. On the transition from mountain to the valley where are located settlements, these torrents deposed sediments that are a result of high intensity erosion processes on the bed and the catchment including weathering, talus cones, landslides and landfalls. Downstream these stream slop in the valley. The most important is that torrent fluids consist of huge quantity of solid material that vary from clay particles up to big boulders (over 15 $m^3$). Somewhere various building built close to the bed even into the bed was ruined. It is result of absence of urban plans for villages. Only damages in Poroj were only on agricultural land and the highway. Villagers faced with torrent in past build houses out of the hazard zone. It is typical how to avoid risk.

Using Aulitzky classification, these torrents are classified as debris flow or debris flood torrents. Torrent index is high and areas near then are assigned as most endangered. According to the torrent character these torrents except river Pena (that is trained with appropriate measures) are assigned as torrents with potential for debris flow/ flood.

Lack of knowledge especially difference between river and torrent hydrology cause designing of not appropriate structures especially with dimension based on calculations of water flow discharge instead of debris flow discharge.

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**Cartographic base data:**

Topographic maps - 1:25000 - several sheets
Geology Map of RM – 1:100 000 – several sheets
Soil Map of RM – 1:50 000 – several sheets
Erosion map of RM – 1:50 000
COPERNICUS EMS data – vector format
Milevski I. - Map of mountains in Macedonia (General geomorphological characteristics of the Republic of Macedonia, 2015)

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