EVALUATION OF WATER EROSION RISK OF BADINSKA RIVER CATCHMENT, SOUTHWEST BULGARIA

Eli Pavlova-Traykova, Assist. Prof., Forest Research Institute, Bulgarian Academy of Sciences (pavlova.el77@gmail.com)
Ivan Ts. Marinov, Prof. DSc., Forest Research Institute, Bulgarian Academy of Sciences
Petar Dimov, PhD Student, Forest Research Institute, Bulgarian Academy of Sciences

Abstract: This investigation has been carried out at Badinska River watershed - one of the most famous torrents in Bulgaria. The purpose of the survey is to analyse the main erosion factors and erosion potential of territories, with a view to assess soil erosion risk and opportunity of high water formation from watershed. A methodical approach for determination and mapping of the territories in terms of the class of erosion risk with the use of GIS is applied. Assessments are made according to the “Methodology for preparing the national long term programme for protection against erosion and flooding in forestlands”. The total assessment for Badinska river watershed is “low to moderate” potential risk and “very low to low” actual erosion risk. About of 5% of the forest stock territory is with “moderate” and “moderate to high” actual risk, and the biggest part of this territory (about 63%) is in the main stream watershed above the Yaloviko tributary.

Key words: soil erosion, water erosion risk, the Badinska River, the Struma River

INTRODUCTION

The assessment of soil erosion risk was made for different purposes and at different levels - field, watershed, regional, national and continental level. For all these purposes, a large number of empirical and physical models are developed – USLE/RUSLE, EUROSEM, K2, etc. (Wischmeier, Smith, 1978, Renard et al., 1997, Morgan et al., 1998, Kirkby et al., 1998, Panagos et al., 2008, Panagos et al., 2012, Karydas et al., 2014 etc.). Many combined approaches are also used (Rahman et al., 2009, Nekhay et al., 2009 etc.).

The current study has a specific purpose, connected with soil erosion risk assessment at the watershed level, but only for forestland territories, the data from which to be used for identification of the hazardous territories and erosion control activities, which are necessary to be performed. In the base of this methodical approach are factors, used in USLE, assessed and mapped with GIS, but with using different approach for assessment of the vegetation cover and soils influence.

Climatic conditions, hilly-mountainous relief of the country and unregulated agricultural and forest activities in the past are the main reasons for soil erosion in Bulgaria. Rainfall erosivity index (R factor), which is the main parameter for soil erosion risk assessment, is with the mean value of 695.0 MJ mm h⁻¹ h⁻¹ yr⁻¹, which is around the mean values for Europe (Panagos et al., 2015). In some regions of the country the intensity of soil
erosion is among the highest in Europe - territories of Regional Forestry Board (RFB) Blagoevgrad, Kardjali, Kyustendil, Sofia and Smolyan (Marinov, Bardarov, 2005, Blinkov et al., 2013).

Strong anthropogenic influence in the past, mainly through grazing, cutting down the forests and nature conditions in Struma river watershed, which is the object of present investigation - Badinska river torrent, have led to deforestation and transformation of some of its tributaries in torrential water flows. At the beginning of the past century a lot of them caused considerable damages on the population, agriculture and forestry. In recent years there are flooded territories and significant material damage, as a result of torrential floods in some of these tributaries. This shows that there is a risk of further floods, and that is why an investigation of forest territory conditions and soil erosion potentials is needed, i.e. potential and actual soil erosion assessment in torrent tributaries of the Struma River. These studies will serve as the base for appropriate action development for the restoration of water regulation and soil protection effects of forest territories.

Potential and actual soil erosion risk assessment by using GIS was made for the Struma River watershed and apparently for some of its tributaries (Stoev et al., 1997, Martensson et al., 1998, Martensson et al., 2001, Marinov et al., 2002a, b, Marinov et al., 2005a, Marinov, Lubenov, 2007). Potential soil erosion risk of upper stream of Struma, where the Dzherman River is, was also studied (Rousseva et al., 2012).

Debris flows are insufficiently studied in the territory of Bulgaria (Gerdjikov et al., 2012), but there are good conditions for their formation in the country mountain watersheds.

The assessment of soil erosion risk for watersheds with torrential character, which in the past have caused damage when they swelled, is very important to determine hazardous territories and necessary erosion control activities at this stage. The purpose of this investigation is to determine the status of the Badinska River watershed, analyzing the main erosion factors with a view to assess potential and actual soil erosion risk in forestlands and to determine the territories with the highest potential of high waters and debris flows formation.

MATERIALS AND METHODS

The object of investigation is the Badinska River catchment area, which is located on southwestern slopes of Rila Mt. It is part of the Dzherman River watershed, tributary of the Struma River. The catchment area is 2117 ha. The torrent became known after disastrous swellings in the 1926-1928 period, when houses were affected, and farmlands and roads were flooded. The Badinska River is a torrent with the highest density of hydrotechnical facilities in the country - there are 62 transversal structures - check dams (barrages), counter check dams and thresholds - in the main stream and tributaries and 16 groins in the sediment cone (Zukov, Marinov, 1978, Marinov, 1997).

In the present investigation, the assessment of potential and actual soil erosion risk was made only for forest lands, applying the “Methodology for preparing the national long term programme for protection against erosion and flooding in the forest lands” (Marinov et al., 2009). The adapted version of the methodology of MERA project was used (Stoev et al., 1997), which was also applied in the Struma River watershed (Martensson et al., 1998), based on the use of GIS opportunities for assessment and mapping the soil erosion factors (rainfalls, topography, soil and vegetation cover).

The application of current methodology gives an opportunity to determine the territories with the risk of soil erosion and also their spatial location in the forestlands (Marinov et al., 2009). Subsection, a unit of the forest management plans, is the main area unit, used in the current investigation.

Precipitation influence on soil erosion development is assessed with the rainfall erosivity index (R factor). A map for area distribution according to the R factor values were used (Rousseva et al., 2010). All areas from forestland with altitudes of 1000 m a.s.l. have annual index of erosion 1 (600 MJ mm/ha h), from 1000 to 1200 m a.s.l. – index 2 (601 – 1000 MJ mm/ha h), and over 1200 m a.s.l. are with rainfall index 3 (1001 – 2000 MJ mm/ha h).

Soil index (Is) is defined for each subsection depending on the erosion degree and erosion type, mentioned in forest management plans. The values obtained by multiplying the class according to the degree of erosion and class according to the type of erosion are divided into three soil in-
dexes – 1 (with value 1), 2 (with value 2 or 3) and 3 (with value 4 and 6). In case there are no data in forest management plans about bare areas, about areas not suitable for forest barrens and areas without information on the degree and type of erosion, soil index \( I_s \) of 2 is accepted, and for gullies, landslides and sliding - the soil index is 3.

For topography factor assessment (slopes gradient), a digital elevation model (DEM) is used, obtained from topography maps with the 1: 25 000 scale. Slope gradient is classified in four indexes: 1 – to 10\(^\circ\), 2 - 11- 20\(^\circ\), 3 - 21 – 30\(^\circ\) and 4 – above 30\(^\circ\).

Potential soil erosion risk is determined by multiplying \( R \) factor, slope index and soil index. Potential soil erosion index is 1 when the value is less than 4, 2 - when the values are from 4 to 9 and 3 - when the values are above 9.

Data from forest management plans were used for vegetation cover influence assessment. Plantations and afforestation with a density above 0.6 have vegetation index 1, with density 0.3-0.6 - index 2, and open stands not suitable for forest areas, barrens, gullies, landslides and landslips - index 3.

Actual soil erosion risk is determined by multiplying the potential soil erosion risk index and the vegetation cover index on a six grade scale - from very low (index 1) to strong (index 6). Assessment for the forest found in the watershed is determined according to the value from the sum of “moderate”, “moderate to strong” and “strong” actual soil erosion risk grade.

For debris flows risk assessment an index obtained from Melton formula - , where \( H_b \) is watershed relief was used, and \( A_b \) is watershed area \((Melton, 1965)\). Watersheds with an index above 0.5 are considered potentially endangered for debris flows formation \((Welsh, Davies, 2011)\).

**RESULTS AND DISCUSSION**

**Watershed characteristics**

The total area of the Badinska River watershed is 2117 ha, of which 1220.1 ha are forestlands (table 1). The altitude at the confluence of the river with the Dzherman River is 385 m, the

highest elevation of the watershed is 1780 m. a.s.l. The average altitude is 866 m. The length of the main water flow is 13.88 km. The density of the hydrographic system is 1.73 km/km\(^2\).

The Badinska River watershed is characterized by steep slopes and active erosion processes. The average slope gradient is 15.7\(^\circ\). There are more sunny slopes along the watershed - they cover an area of 1267.6 ha, which together with the steep slopes makes unfavorable conditions for vegetation and soil formation.

The main soil types in the catchment area are eroded and leached cinnamon, brown forest and mountain-meadow. Cinnamon forest soils are the most common soil type in the country – covering 21.7% from the total area of the country \((Marinov et al., 2005b)\). In the catchment area they occupy 1163.3 ha, which is 54.9% of the watershed area, and they are in the regions up to 800 m. a.s.l., and in southern exposure they are up to 1000 m. a.s.l., 506.0 ha from the watershed are with brown forest soils. On the northern slopes they are located above 800 m a.s.l., on the southern ones - above 1000 m a.s.l.
The main tree species on the watershed are *Quercus petraea* Liebl., *Fagus sylvatica* L., *Pinus sylvestris* L. and *Pinus nigra* Arn., with a lower participation of *Quercus frainetto* Ten., *Carpinus orientalis* Mill., *Quercus pubescens* Willd. and *Quercus cerris* L.

One significant part of the watershed is on Pliocene deposits, which created favorable conditions for erosion development. Typical of the watershed is the presence of many landslides. The reason for them is very steep slopes and water flow meander. The main water flow and the tributaries continually undermine banks, and in this way little landslides are formed, which are a source of sediments.

### Potential and actual soil erosion risk

The area of distribution of individual soil erosion factors (characterized with erosivity, soil and slope indexes), involved in determining potential soil erosion risk is presented in table 2. Distribution according to rainfall erosivity index ($R$ factor) was made for the entire watershed. Soil and slope indexes are determined for the forestlands. The obtained data for the main factors that determine potential soil erosion risks are as follows: the biggest share have the territories with “low to moderate” and “moderate” erosion rainfalls (index 1), which occupy 72.0% of the total watershed area. On 18.7% of the total area there are “very strong” erosion rainfalls, and about twice smaller are territories with “moderate to strong” and “strong” erosion rainfalls.

The data about the soil index were obtained from forest management plans, showed that in the watershed forestlands, the biggest share belongs to terrains without erosion – 1012.0 ha, which is 82.9% of its total area. Soil erosion on 13.3% of the territory is estimated as low and 3.8% - as strong from 4 and 5 degrees.

The forest stock is mainly on steep and very steep slopes above 20º (tabl. 2). The territories with slopes from 21 to 30º (index 3) occupy the biggest part of the area (672 ha), which is 55% of...
the total forest stock area and the territories with slopes above 30º are 36%. The large area with very steep slopes (about 90% of the forestland area is with slopes above 20º) distinguished slope as main potential factor for the development of erosion processes in the Badinska River watershed. This is the conclusion also for the entire Struma River watershed, the Badinska River being part of it (Martensson et al., 2001).

Forest stock distribution by potential erosion degree shows that 56.8% of the territory is with “low” potential soil erosion risk, 38.0% - with “moderate” and only 5.2% - with a “strong” potential soil erosion risk (table 3). Soil erosion risk results for the territories above the Yaloviko tributary (L3) show that there is an increasing percentage participation of “moderate” and “strong” potential soil erosion risk. “Moderate” risk was found in 60% of the territory and 18.8% of it is characterized by a “strong” potential soil erosion risk. In Siracov anduc tributary (L31) the risk is “low”, in Shipoka (L32) the territories with “low” and “moderate” risk are almost with the same area, and in the Sindzhirov dol tributary (L33) about 2/3 of the area is with “moderate” potential soil erosion risk.

In the mountainous regions, the main factor of erosion control is forest cover, which is also determining the actual soil erosion risk assessment. The new afforestation on degraded lands has significant role for the smaller degree of actual soil erosion risk. The main goal of afforestation was to restrict the erosion and improve soil conditions rather than timber production. That was a driving key for tree species selection. Anti-erosion afforestation in the watershed is mainly with Pinus sylvestris L., Pinus nigra Arn. and Robinia pseudoacacia L. These tree species are tolerant to soil conditions and Robinia pseudoacacia L. has significant strengthening effect on landslides. The total area of erosion control afforestation is 113 ha with Pinus sylvestris L., 97.5 ha – with Pinus nigra Arn. and 79.5 ha with Robinia pseudoacacia L. Black locust afforestation in the watershed are mainly on the right banks of the main stream and they are carried out to strengthen sliding terrains.

<table>
<thead>
<tr>
<th>Rainfall erosivity index (R factor)</th>
<th>Area ha</th>
<th>Soil index (Is)</th>
<th>Area ha</th>
<th>Slope index</th>
<th>Area ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1525</td>
<td>1</td>
<td>1011.5</td>
<td>1</td>
<td>18.8</td>
</tr>
<tr>
<td>2</td>
<td>197</td>
<td>2</td>
<td>162.7</td>
<td>2</td>
<td>91.9</td>
</tr>
<tr>
<td>3</td>
<td>395</td>
<td>3</td>
<td>45.9</td>
<td>3</td>
<td>671.6</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>437.8</td>
</tr>
<tr>
<td>Total area</td>
<td>2117</td>
<td>-</td>
<td>1220.1</td>
<td>-</td>
<td>1220.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential soil erosion risk</th>
<th>Badinska river watershed</th>
<th>Main stream watershed to Yaloviko tributary (l31)</th>
<th>Pechan dol watershed (l32)</th>
<th>Pesoco watershed (l3)</th>
<th>Yaloviko watershed (l33)</th>
<th>Yaloviko watershed tributaries (L3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>Degree</td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>1</td>
<td>Low</td>
<td>655</td>
<td>56.8</td>
<td>41.9</td>
<td>20.4</td>
<td>17.1</td>
</tr>
<tr>
<td>2</td>
<td>Moderate</td>
<td>438.1</td>
<td>38</td>
<td>124.4</td>
<td>60.7</td>
<td>21.1</td>
</tr>
<tr>
<td>3</td>
<td>Strong</td>
<td>59.9</td>
<td>5.2</td>
<td>38.5</td>
<td>18.8</td>
<td>-</td>
</tr>
<tr>
<td>Total area</td>
<td>1153.1</td>
<td>100</td>
<td>204.8</td>
<td>100</td>
<td>38.2</td>
<td>100</td>
</tr>
</tbody>
</table>
The results from vegetation index show that almost all forestland territory (98%) is covered with plantation and afforestation with density above 0.6, which means that there is full protection from erosion (table 4). About 10% of the forest stock is with poor protection and under 1% of the territory are under moderate protection.

Forestland territory distribution according to the actual soil erosion risk is shown in table 5 and spatial distribution – in figure 2. The assessment of forestland territory for actual soil erosion risk distribution is “very low” to “low” actual soil erosion risk in 86.6% of the total area. This is due to erosion control afforestation and better conditions for forest vegetation in the last decades, mainly because of grazing restriction. The transversal facilities also take part in the stabilization of the area around water current and set up conditions for the improvement of soil protection effectiveness of erosion control afforestation. The transversal activities stopped the processes of destruction and washing-out of materials and stabilized the banks. About only 5% of the forest stock area is with “moderate” and “moderate to strong” actual soil erosion risk, which is 56.7 ha, biggest part of this area is in the main watershed above the Yaloviko tributary (table 5). Regardless of the small area of these territories, their presence is an indicator of possibilities of significant water flow formation and washing-out of materials, with a view to pliable geological base. This points to the necessity of additional erosion control activities.

Actual soil erosion risk assessment for the total area of the Struma River watershed is “low to moderate” (Marinov, Lubenov, 2007). In the present investigation actual soil erosion risk assessment for the Badinska River watershed is “very low to low” because of large scale erosion control activities in the past on the one hand, and methodical approach on the other - only the forest stock, where forest vegetation covered the biggest part from the territory is estimated and this restricts the risk.

### Table 4. Forest stock territory distribution by vegetation index

<table>
<thead>
<tr>
<th>Vegetation index</th>
<th>Type of subsection</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Plantation and forestation with density above 0.6</td>
<td>1100.2</td>
</tr>
<tr>
<td>2</td>
<td>Plantation and forestation with density above 0.3 - 0.6</td>
<td>7.6</td>
</tr>
<tr>
<td>3</td>
<td>Open stands, not suitable for forest land, barren, gullies, burnt out area, soles, landslides, screes, landslips, embankment, marshes, cutting area.</td>
<td>112.3</td>
</tr>
</tbody>
</table>

### Table 5. Forestland distribution by actual soil erosion risk

| Actual soil erosion risk | Badinska river watershed | Main stream watershed to Yaloviko tributary (L1) | Pehchandoel watershed (L2) | Pesoco watershed (L2) | Yaloviko watershed (L3) | Yaloviko tributaries (L3) | Degree | Index | ha | % | ha | % | ha | % | ha | % | ha | % | Ha | % | ha | % | Ha | % |
|--------------------------|--------------------------|-----------------------------------------------|---------------------------|------------------------|------------------------|-------------------------|--------|-----|----|---|----|---|----|---|----|---|----|---|----|---|----|---|
| Very low                 | 1                        | 591.8                                        | 34.8                      | 17                     | 15.9                   | 41.7                    | 129.9  | 66  | 182.8 | 46.5 | 75.2 | 17.7 | 39.6 | 9.8 | 13.6 |
| Low                      | 2                        | 407.1                                        | 35.3                      | 103.4                  | 50.5                   | 21.1                    | 55.3   | 28.1 | 159.4 | 40.5 | 6    | 20.2 | 45   | 53.9 | 74.6 |
| Low to moderate          | 3                        | 97.5                                         | 8.5                       | 30.7                   | 15                     | 1.2                     | 3.1    | 9.4  | 4.8  | 34.8 | 8.9  | 4.8  | 5.5  | 5.2  | 11.6 | 5.4  | 7.5  |
| Moderate                 | 4                        | 37.7                                         | 3.3                       | 23.7                   | 11.6                   | -                       | -      | 2.2  | 1.1  | 9.6  | 2.4  | 0.5  | 0.6  | 1.7  | 3.8  | 2.2  | 3    |
| Moderate to strong       | 5                        | 19                                           | 1.6                       | 12.2                   | 5.9                    | -                       | -      | -    | -    | -    | 6.8  | 1.7  | -    | -    | -    | 1    | 1.4  |
| Total area               | 1153.1                   | 100                                          | 204.8                     | 100                    | 38.2                   | 100                     | 196.7  | 100  | 393.5 | 100  | 86.5 | 100  | 44.8 | 100  | 72.3 | 100  |
The spatial distribution of forestland by actual soil erosion risk shows that the territories with “moderate” and “moderate to strong” actual erosion risk are mainly in the upper part of the watershed, where slopes are steep and there are more bare areas (non-suitable for forest area, gullies and landslides) (fig. 2).

Vegetation cover has major influence on soil erosion risk restriction. Statistical analysis of a huge data base for many European countries shows the dominant influence of land use and cover on soil erosion rates (Cerdan et al., 2010). Lands with permanent vegetation cover (bushes, grasslands and forest territories) are characterized by significantly less soil loss compared to arable lands. Forest vegetation is the major factor for soil erosion restriction in torrential watersheds. Therefore, to change torrent characteristics of water flows, we need afforestation on forest stock bare lands and eroded areas. There is an interest in changing the actual erosion rates in case there is no afforestation in the watershed. Table 6 shows the change in the assessment when there is no afforestation. In the lower part of the watershed, under the Yaloviko tributary (L3), territories with “moderate” and “moderate to strong” increased from 5 to 12.1% for the total forest fund area. In the upper part of the watershed there are no significant changes, because afforestation is lower there.

Spatial distribution of the territory by actual erosion risk rates without erosion control affores-

Table 6. Forestland distribution by actual erosion risk without anti-erosion afforestation

<table>
<thead>
<tr>
<th>Actual soil erosion risk</th>
<th>Index</th>
<th>Badinska river watershed</th>
<th>Main stream watershed to Yaloviko tributary (L1)</th>
<th>Pehchan dol watershed (L2)</th>
<th>Pesoco watershed (L2)</th>
<th>Yaloviko watershed (L3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
<td>ha</td>
</tr>
<tr>
<td>Very low</td>
<td>1</td>
<td>421.2</td>
<td>36.5</td>
<td>34.7</td>
<td>17</td>
<td>10.6</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
<td>321</td>
<td>27.8</td>
<td>103.4</td>
<td>50.5</td>
<td>13</td>
</tr>
<tr>
<td>Low to moderate</td>
<td>3</td>
<td>271.7</td>
<td>23.6</td>
<td>30.8</td>
<td>15</td>
<td>6.5</td>
</tr>
<tr>
<td>Moderate</td>
<td>4</td>
<td>119.8</td>
<td>10.4</td>
<td>23.7</td>
<td>11.6</td>
<td>8.1</td>
</tr>
<tr>
<td>Moderate to strong</td>
<td>5</td>
<td>19.4</td>
<td>1.7</td>
<td>12.2</td>
<td>5.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Total area</td>
<td>1153.1</td>
<td>100</td>
<td>204.8</td>
<td>100</td>
<td>38.2</td>
<td>100</td>
</tr>
</tbody>
</table>
Debris flows

Key factors of debris flow formation are steep slopes and easily prone to soil and rock erosion. These flows are formed when slopes are above 15°, and they are more likely to occur in the upper parts of the watersheds, where slopes are usually steeper and this is typical of the first grade tributaries. Another factor for debris flows formation is generating of large surface flow, which is the result of torrential precipitations on the watershed territories. Biolchev (1996) pointed out the Badinska River as one of the watersheds, where debris flows are formed.

According to the Melton index of assessment, in the upper part of the Badinska River watershed, there is a high possibility of debris flows formation (table 7) above the Yaloviko tributary. The reason for the high index (0.51) are steep slopes in this part of the watershed. Another reason for debris flow formation is the processes of intensive erosion. Results for actual soil erosion risk in the watershed show that in the upper part actual soil risk is the highest, and also in the same area there is a high possibility of debris flows, because of the highest rates according to the Melton index assessment.

CONCLUSION

The assessment of erosion risk is made according to the “Methodology for preparing the national long term programme for protection
against erosion and flooding in forestlands”. To determine soil erosion risk, data about the main erosion factors (precipitations, vegetation, soils and slope gradient) are used, and they are also assessed and mapped by GIS. However, a specific approach for vegetation cover and the impact of soils is used.

The final assessment of soil erosion risk in the Badinska River watershed is “low to moderate” potential soil erosion risk and “very low to low” actual erosion risk. The results showed that regardless of the low rates of actual risk for the total area of the watershed, in the upper part there are territories with the highest erosion risk. The areas from the upper part of the watershed with “moderate” and “moderate to strong” actual erosion risk are the same as the territories with risk of debris flow formation.

Significant influence of forest vegetation has been confirmed and mainly of erosion control afforestation on erosion restriction in mountainous territories and on changing the character of torrent watersheds, which leads to actual erosion risk reduction.

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