RESEARCH ARTICLE **(Open Access)**

Potential soil erosion and sediment yield in Bovilla watershed. Soil erosion and sediment yield in Bovilla watershed

VALMIR BALOSHI[1], FRAN GJOKA[1]*, ELVIN TOROMANI[1], NEHAT ÇOLLAKU[1]

[1]Agricultural University of Tirana, Kodër Kamëz, Tirana, Albania

*Corresponding author; E-mail: rimlav_2004@hotmail.com

Abstract

Sediments and chemical pollutants generated by soil erosion penetrate into the water bodies damaging their quality. In this study, the potential soil loss and sediment yield has been investigated at the sub-watershed level within Bovilla watershed located in the northeast of Tirana municipality. This reservoir provides most of the potable water for Tirana city. Data on local rainfall, soil type, topography, land cover and conservation practices were used for soil erosion modelling using the integration of RUSLE and ArcGIS tools. The sediment delivery ratio was determined by several models to obtain the sediment yield. The potential annual soil loss was highly variable, ranging from 2.46 to 37.72 t/ha/year. The lowest value (0.2 t/ha/year) in annual soil loss is reached in the Bulcesh sub-watershed and highest (1.2 t/ha/year) in Ranza sub-watershed because of the presence of steep slopes. The mean sediment yield in this watershed for the four tested models ranged from 7.15 to 43.25 t/ha/year. This high variation is the result of the diverse land covers/uses, wide range of land slopes and distances to drainage channels within each sub-watershed. The sub-watershed 'Ranxe' with the highest slope had the maximum sediment yield, contributing to approximately 30% of the total sediment yield in Bovilla watershed. Several sub-watersheds like "Ranxe", "Vilez" and "Zall-Bastar" were identified as critical erosion areas, accounting to 78% of the total sediment yield at watershed level, threatening the water quality of Bovilla reservoir. In these critical areas, immediate measures are needed to protect soil and improving water quality. However, further research is needed to quantify soil losses at experimental plots as well as to determine the chemical parameters of water quality in the watershed scale.

Keywords: land cover, RUSLE, sediment yield, soil erosion, water quality.

1. Introduction

Soil erosion is a complex dynamic process by which soil particles are detached, transported and accumulated in a distant place. The final result of this is the exposure of top soil layers and their sedimentation to reservoir. In mountainous areas water flows from the upper stream and transport sediments which usually are entrapped in drainage channels, outlet of water courses and the rest deposited into the reservoir. Sedimentation in Bovilla reservoir has caused many problems in water quality, decreasing the storage capacity and water supply for population as result of turbidity raising. It's complicated to model soil erosion due to the numerous factors which accelerate the erosion process [14]. Many soil erosion models have been developed ranging from simple empirical equations such as the Universal Soil Loss Equation (USLE) [13] and its revised version RUSLE [9]. The USLE equations provides an estimation of the sediments mobilized by surface runoff, but is not able to model or predict whether sediment will be exported out of the catchment or deposited as colluvium or alluvium within the Bovilla catchment [4]. Main objectives of this study were: (i) to estimate the spatial soil loss in Bovilla watershed by using the RUSLE model and identify the critical erosion areas; and (ii) to determine the sediment delivery ratio and sediment yield, which ultimately affects the sedimentation quantity to Bovilla reservoir.

2. Material and Methods

2.1 Description of the study area

The study area situated in the north-east part of Tirana city is located between 41° 15' - 41°30' north latitude and from 19°50' to 20° 05' east longitude (Figure 1). Bovilla watershed area is 95 km^2, where 52.2 km^2 belongs to

Tirana municipality and the rest to Kruja municipality. The Bovilla reservoir is 15 km far away from Tirana city with a maximum water filling capacity of 80 Million cubic meter. The total area of Bovilla reservoir is 4.6 km^2 and the maximal depth is 53 m.

Figure 1. Location and physical map of the Bovilla watershed

The climate of the study area is Mediterranean with relatively cold, wet winters, and warm, dry summers. Bovilla watershed has a wide altitudinal range affecting directly the local climate. The mean annual temperature is 13.9°C and the annual sum of rainfall is 1718.6 mm. Rainfall data are characterized by a non-uniform monthly distribution. Most of the precipitation falls during autumn and winter months being an important water supplier for the hydrologic network in the Bovilla watershed**.** Geologically, the Bovilla watershed can be divided into two distinct areas: (i) peripheral area of watershed consisting predominantly by carbonate deposits - limestones and dolomites and minor amounts of quaternary deposits - clays, alevrolites, sands and (ii) central area of watershed consisting mainly of flysch. The study area has a dissected topography and comprised a variety of landforms like mountains, hills and valleys. Based on the built DEM, around 80% of the Bovilla watershed has an inclination from 15 to 30 degrees. The elevation range in vary from 300 to 1800 m above sea level (m a.s.l.) Eighty percent of the watershed area has an altitude ranged from 300 to 1000 m a.s.l. There are three main soil groups in the study area: Leptosol (Calcaric), Cambisol (Calcaric) and Phaeozem (Calcaric). The cambisol (Calcaric) was found in the north and northeastern parts of the watershed on step slopes and was developed especially on flysch formation and carbonate deposition, leptosol (calcaric) dominates the central-southern and southwestern parts of the watershed on relative steep slopes and was developed especially on flysch formations, and phaeozem (Calcaric) in the northwestern part of the watershed on steep slopes and on flysch rocks and carbonate deposition.Total area of the watershed is 9457 ha dominated by broadleaves forest, pastures, riparian vegetation and agriculture lands.

2.2. Methods

In order to estimate the potential soil loss was used the RUSLE model [9]. This model was integrated with ArcGIS to estimate soil erosion within the raster/grid built for study area. The computation of the potential annual soil erosion was done using the following equation:

$$A = R \times K \times S \times L \times C \times P$$

where:
A - the average annual soil erosion (t/ha $year^{-1}$).
R - the rainfall erosivity factor (MJ mm)/(ha h $year^{-1}$).
K - the soil erodibility factor (t ha h)/(ha MJ mm).
LS - the slope length and steepness factor (dimensionless).
C - the crop management factor (dimensionless).
P - the support practice factor (dimensionless).
The model parameters were computed using: (i) rainfall data for estimation of rainfall erosivity factor (R); (ii) soil map, field and laboratory measurements for soil erodibility factor (K); (iii) digital elevation model (DEM) data for estimation of slope-length factor(LS), and (iv) satellite images to estimate crop management factor (C).

2.2.1. Rainfall erosivity factor (R)

Rainfall erosivity factor was determined using the following equation [8]:

$$R = I_{30} (9.28P - 8383)/1000$$

where:
I_{30} = 75 mm / h (value recommended by [13].
P = average annual precipitation (mm) over the last 35 years
Annual rainfall data acquired over the last 35 years were provided from the CRU TS 3.24 climate dataset from the nearby grid points with the study area.

2.2.2. Soil erodibility factor (K)

Soil erodibility factor is computed as a function of soil properties such as: texture, organic matter content, structure and permeability using following equation [7].

$$100K = \frac{[2.1 \cdot M^{1.14} \cdot (10^{-4}) \cdot (12 - OM) + 3.25 \cdot (S - 2) + 2.5 \cdot (p - 3)]}{7.59}$$

where:
K - erodibility factor (t ha h).
M - particle size parameter (adjusted by Goldman 1985) ($M = P_{silt} \cdot (100 - P_{clay})$.
OM - organic matter content (%).
S - soil structure code.
P - permeability class.

2.2.3. Length and slope factor (LS)

The effect of topography on soil erosion in RUSLE model is accounted for by the LS factor. The slope length factor (L) is calculated using following equation [11].

$$LS = [0.065 + 0.0456 \cdot Slope + 0.0065 \cdot (slope)^2] \cdot \left(\frac{slopelength}{22.1}\right)^{0.5}$$

The LS-factor value is computed for each grid cell, and then the LS-factor map for entire the watershed is obtained

2.2.4. Crop management factor (C)

To determine the C factor, parameters such as amount of annual soil erosion (A), rainfall erosivity factor (R), soil erodibility factor (K), topographic factor (LS) and support practice factor (P) are measured from monitoring erosion plots. The volume of soil loss was multiplied with bulk soil density values derived from soil samples collected in the Bovilla area to estimate the soil loss in weight unit per sample plot and then extrapolated per 1 ha area.

2.2.5. Support practice factor (P)

The P factor explains the influence of conservation practices on soil loss. It is closely related to agriculture land ploughing direction, specific cultivation and conservation practices. In order to ascertain the P values for the study area we used the information provided during our field visits and interviews with farmers related to agriculture land utilisation and land management practices. The land ploughing along the slope was the dominant practice in the study area and most of the agriculture crops are: maize, wheat, vegetables, and beans. In our study we used the P factor values considering the local management practices and based on values suggested by Eweg and Van Lammeren [3] we estimated the weighted P value for main land use categories such as: agriculture land, forest land, bare land, etc.

2.3. Sediment Yield (SY)

Sediment yield was estimated based on the sediment delivery ratio and potential soil loss estimated by RUSLE model, using the following equation.

$$SY = SDR \times A$$

where:
SY - sediment yield (ton ha^{-1} yr^{-1})
SDR - sediment delivery ratio.
A- potential annual soil loss (ton ha^{-1} yr^{-1}).
Sediment delivery ratio (SDR) represents the ratio of sediments delivered to a stream or outlet to the total erosion from the contributing areas. It is commonly used as indicator of sediment transport efficiency of watersheds (Dickinson and Collins [2]. SDR was estimated using four models proposed by: (i) Manner [6] ; (ii) Renfro [10]; (iii) Vanoni [12] and (iv) Boyce [1].

3. Results and Discussion

3.1. Estimation of soil loss

Based on the calculation of each factor of the RUSLE model was generated the soil erosion map (Fig. 2). This map was generated by cell to cell multiplication overlay of the raster (grid) maps of the five RUSLE input parameters. The map of spatial distribution of gross erosion clearly demonstrates that soil loss less than 2.46 tons/ha/yr covers only 3.63% of the study area. Previous studies have reported that mean rate of soil loss in the European Union countries was 2.46 t/ha/year [7]. The maximum soil loss was found in the mountainous areas with LS Factor values greater than 15.2. The most vulnerable areas to erosion (over 2.46 t/ha/year) are considered as areas with a risk of on ecosystem services. Soil losses higher than 1 t/ha/year are considered irreversible within a period of 50-100 years [4].

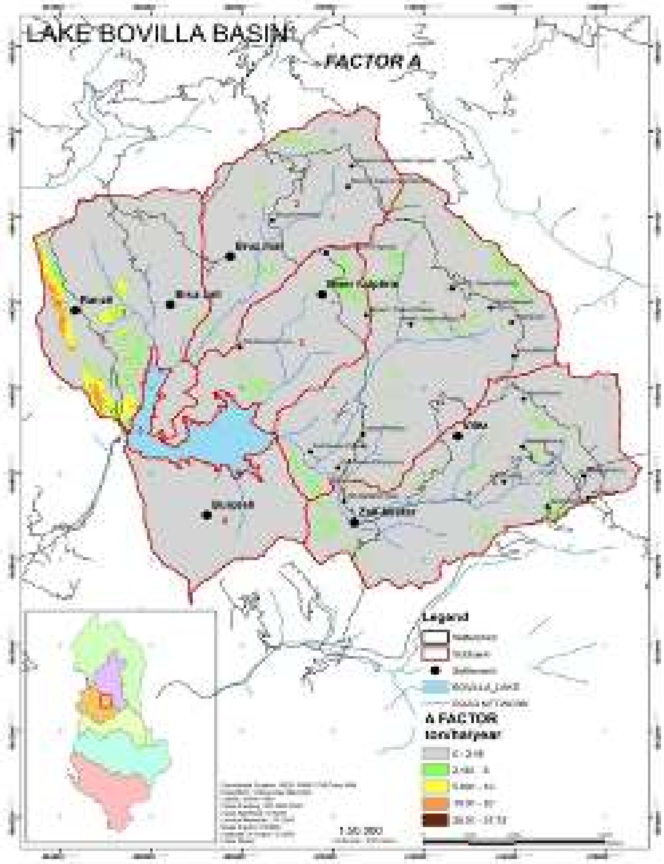

Figure 2. Map of the spatial distribution of soil loss in Bovilla watershed

We classified the soil loss values calculated from RUSLE model for Bovilla watershed potential into 5 classes (Table 1).

Table 1. Soil erosion classes of the study area

Erosion class	Soil loss (t/ha/yr)	Erosion potential
I	< 2.46	very low
II	2.46-5	low
III	5.01-10	moderate
IV	10.1-20	high
V	20.1-37.72	very high

The soil loss varied between sub-watersheds and range from 0.2 at the Bulcesh sub-watershed to 1.2 t/ha at the Ranze sub-watershed, while the mean soil loss is 0.79 t/ha (Table 2).

Table 2. Soil loss values for each sub-watershed

Name of Sub-Watershed	**Area (ha)**	**Average soil loss (tons/ha/y)**	**Total Soil loss (ton)**
Ranxe	1,626.26	1.2	1951.5
Bruz Mal	1,422.95	0.6	853.8
Mner i Siperm	967.41	0.8	773.9
Vilez	2,343.93	0.8	1875.1
Zall-Bastar	1,979.42	0.8	1583.5
Bulcesh	829.48	0.2	165.9
Total	**9515.2**	**0.79**	**7203.8**

3.2. Estimation of sediment delivery ratio

Sediment delivery ratio (SDR) was estimated after the division of the study area into six sub-watersheds using four empirical models (Table 3).

Table 3. SDR values computed by different models

Local Name (village)	Area (ha)	SDR (%)			
		Maner [6]	Renfro [10]	Vanoni [12]	Boyce [1]
Bovilla Reservoir	345.78	2.52	5.2	5	3.7
Ranxe	1,626.26	36.8	41.8	41	29.5
Bruz Mal	1422.95	31.2	42.6	40	30.6
Mner I Siperm	967.41	27.8	45.0	42	31.5
Vilez	2,343.93	34.6	39.7	40	31.6
Zall Bastar	1,979.42	33.6	40.6	41	29.4
Bulcesh	829.48	34.7	46.0	42	32.2
Mean SDR value	**9515.23**	**32.4**	**40.5**	**39.5**	**29.7**

Bulceshi sub-watershed has the highest SDR value based on the calculations of all models and this can be explained due to the short distance from Bovilla reservoir and the wide range of slope (from 13 to 98.7%). It's widely known that shorter distances and steeper terrains increase the sediments transport speed and as consequence the deposition to reservoir. The same logical approach is useful also for Ranxe sub-watershed, but the SDR value in this case is a bit lower than the previous one. Another sub-watershed with high SDR value identified by three models is Mner i Siperm, but its value is lower than Bulcesh and Ranxe, because it has a moderate slope and is distantly located from the Bovilla reservoir.

3.3 Sediment yield

Sediment yield was estimated as a product of soil loss and sediment delivery for each sub-watershed. Based on the estimations of soil loss and sediment delivery for each sub-watershed we have determined the sediment yield. Table 4 shows that exist high variations in the estimated sediment yield within each sub-watershed. The difference in sediment yield is caused due to the different characteristics of each sub-watershed such as: vegetation cover, slope, aspect, amplitude of elevation and distance from watercourse and Bovilla reservoir.

Table 4. Estimation of sediment yield per 1 ha for each sub-watershed

Sub-watershed	Area (ha)	Mean A (tons/ha)	SDR (%)				Sediment Yield (tons/ha)			
			Maner [5]	Renfro [10]	Vanoni [12]	Boyce [1]	Maner [5]	Renfro [10]	Vanoni [12]	Boyce [1]
Bovilla reservoir	345.78	0.0	2.52	5.2	5.0	3.7	0.0	0.0	0.0	0.0
Ranxe	1626.26	1.2	36.8	41.8	41.0	29.5	44.2	44.2	49.2	35.4
Bruz Mal	1422.95	0.6	31.2	42.6	40.0	30.6	18.7	18.7	24.0	18.4
Mner I Siperm	967.41	0.8	27.8	45.0	42.0	31.5	22.2	22.2	33.6	25.2
Vilez	2343.93	0.8	34.6	39.7	40.0	31.6	27.7	27.7	32.0	25.3
Zall Bastar	1979.42	0.8	33.6	40.6	41.0	29.4	26.9	26.9	32.8	23.5
Bulcesh	829.48	0.2	34.7	46.0	42.0	32.2	6.9	6.9	8.4	6.4

3.4 Critical erosion areas

Based on the sediment yield and drainage area, the sub-watersheds 'Ranxe', 'Vilez' and 'Zall-Bastar.' were selected as critical erosion areas, which contribute to about 78% of total sediment yield of the watershed. The 'Ranxe' sub-watershed contributes to approximately 30% of the total sediment yield in Bovilla watershed (Fig. 3). In these critical areas, immediate measures are needed to protect soil and water.

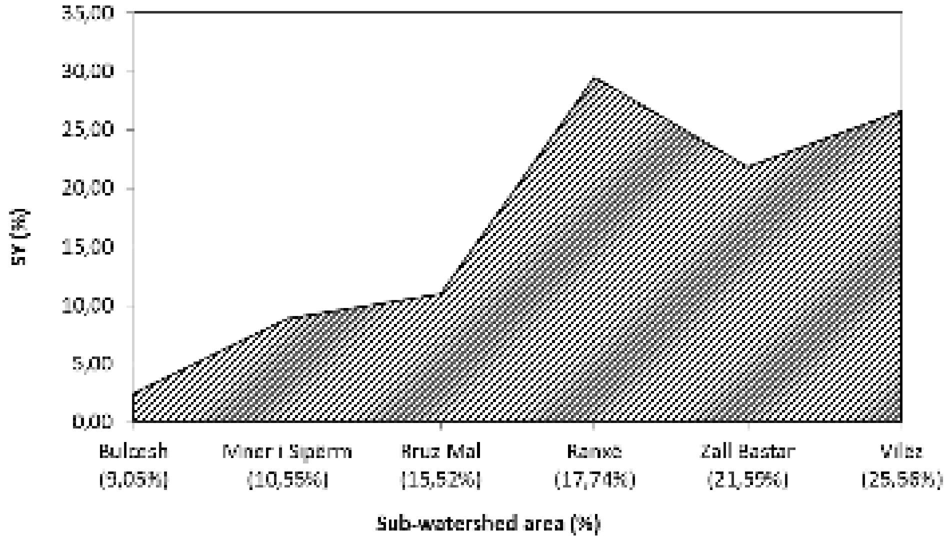

Figure 3. Relative contribution of sub-watersheds to total sediment yield

4. Conclusions

Potential soil loss in Bovilla watershed was estimated by integrating RUSLE equation with ArcGIS tools. The final output of this approach is identification of critical erosion areas, and this information will be used to propose the cost-effective measures to reduce soil loss. Bovilla watershed is prone to erosion ranging from very low to very high erosion classes accounted to about 78% of the total watershed area. Different critical erosion areas were identified in Bovilla watershed mainly located in steep slopes with poor vegetation cover and fragile soils with low clay content. Soil loss resulted variable between sub-watersheds due to their differences in site characteristics. From the results of this study, it is clear that RUSLE-GIS model is a useful tool for the qualitative as well as quantitative assessment of soil erosion with reasonable accuracy. Sediment yield estimated based on SDR values was used to identify sub-watersheds where preventing erosion measures are required. These sub-watersheds are: Ranxe, Vilez and Zall-Bastar and cover 65% of the Bovilla watershed and provide nearly 78% of the total sediment yield accumulated to Bovilla reservoir.

5. Acknowledgements

The authors thank the Payment for Environment Services Project of World Bank for the support of this study.

6. References

1. Boyce R.C: **Sediment routing with sediment delivery ratios**. In present and prospective technology for predicting sediment yields and sources.ARS-S-40, USDA-ARS.1975.
2. Dickinson A, Collins R: **Predicting erosion and sediment yield at the catchment scale**. In F.W.T. Penning de Vries, F. Agus, & J.Kerr (Eds.), Soil erosion at multiple scales: principles and methods for assessing causes and impacts (pp. 317–342). CAB Publishing, Wallingford, UK in association with the International Board for Soil Research and Management.1998.
3. Eweg H, Van Lammeren R: **The application of a geographical information system at the rehabilitation of degraded and degrading areas. A case study in the highlands of Tigray, Ethiopia**. Centre for Geographical Information Processing, Agricultural University Wageningen. 1996.
4. *Grimm, M., Jones, R.J.A., Montanarella, L:* ***Soil erosion risk in Europe. European Soil Bureau****. EUR 19022 EN, 2001, 38pp.*

5. Hui L, Xiaoling C, Lim K. J, Xiaobin C, Sagong M: **Assessment of soil erosion and sediment yield in Liao watershed, Jiangxi Province, China, Using USLE, GIS, and RS**. *Journal of Earth Science* 2010. 21: 941-953. doi: 10.1007/s12583- 010-0147-4.
6. Maner S.B: **Factors influencing sediment delivery rates in the Red Hills physiographic area**: Transaction American Geophysical Union, 1958. 39: 669-675.
7. *Panagos P, Borrelli P , Poesen J , Ballabio C , Lugato E , Meusburger K , Montanarella L , Alewell C:* ***The new assessment of soil loss by water erosion in Europe****. Environmental Science & Policy 2015, 54:438–447. http://dx.doi.org/10.1016/j.envsci.2015.08.012.*
8. Ramírez, O.A.F: **Evaluación del riesgo por erosión potencial de la zona cafetera central del departamento de Caldas**. Trabajo de grado Ingeniero Forestal. Facultad de Ingeniería Forestal. Universidad del Tolima. Ibagué.pg 98.2006.
9. Renard K.G, Foster G.R, Weesies G.A, McCool D.K, Yoder D.C : **Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE).** USDA Agriculture Handbook, p.703. 1997.
10. Renfro W. G: **Use of erosion equation and sediment delivery ratios for predicting sediment yield**. In: Present and Prospective Technology for Predicting Sediment Yields and Sources. US Dept. Agric, Publ. 1975. ARS-S-40, 33-45.
11. Stone R. P, Hilborn D: **Universal Soil Loss Equation (USLE) factsheets**. Queen's printer for Ontario, pg 1-8. 2012. ISBN 1198-712x.
12. Vanoni A: **Sedimentation Engineering**. Manuals and reports on engineering practice No 54. American Society of Civil Engineering, New York.1975.
13. Wischmeier W.H, Smith D.D.: **Predicting rainfall erosion loss. A guide to conservation planning.** USDA Agriculture Handbook no. 537, Washington, DC. 1978.
14. Zhu AX, Wang P, Tongxin Zh, Lajiao Ch,Qiangguo C, Huiping L: **Modeling runoff and soil erosion in the Three-Gorge Reservoir drainage area of China using limited plot data**. Journal of Hydrology 2013, 492: 163-175.