Available online at http://www.journalcra.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 12, Issue, 08, pp.13351-13358, August, 2020

DOI: https://doi.org/10.24941/ijcr.39529.08.2020

ISSN: 0975-833X

RESEARCH ARTICLE

MORPHOMETRIC ANALYSIS OF RUNOFF CONTRIBUTING WATERSHED TO ADAMA-ASELLA ROADSIDE SOIL EROSION AND ITS PRIORITIZATION FOR INTERVENTION

*Kossa Terefe Abebe

Lecturer, Department of Natural Resources Management, Arsi University College of Agriculture and Environmental Science

ARTICLE INFO

Article History:
Received 05th May, 2020
Received in revised form
27th June, 2020
Accepted 14th July, 2020
Published online 30th August, 2020

Key Words:
Adama-Asella, Roadside, Runoff, Hate, Deya, Highway.

ABSTRACT

Soil erosion has been recognized as a serious socio-economic problem in Ethiopia.. Roadside soil erosion of Adama-Asella highway is among the problems affected the traffic from the two zones to the country's capital city, Addis Ababa. Studies concerning the alignment of the road versus natural runoff flow has not been studied. The objective of this study was to characterize runoff contributing watershed to the Adama-Asella roadside erosion and prioritize of its micro-watersheds for watershed management intervention. To identify runoff contributing watersheds and extraction of drainage lines, area encompassing the damaged road were delineated using DEM. By overlaying natural runoff flow lines of the watershed against the road alignment was evaluated in the GIS. To analysis morphology of the micro-watersheds, areal, linear and relief aspects were used. Using compound values of 4 linear parameters, 4 shape parameters and 1relief parameter, prioritization of four micro-watersheds (MW1, MW2, MW3 and MW4) connected to the road were done. The study identified that micro-watersheds MW3 is the highest priority micro-watershed while MW4 is the least priority micro-watershed. MW1 and MW2 are the second and third priority micro-watershed, respectively. Therefore, implementation of watershed management intervention per the identified priority micro-watershed is important.

Citation: ***Kossa Terefe Abebe*. 2020.** "Morphometric analysis of runoff contributing watershed to adama-asella roadside soil erosion and its prioritization for intervention", *International Journal of Current Research*, 12,(08), 13351-13358.

INTRODUCTION

Soil erosion is a serious problem throughout the world (1). Though its effect is more prevailed in agricultural production, it has created widespread ecological and economic impacts (2). To control soil erosion problem, various strategies have been designed in different countries. Watershed management approach is among the strategies has been implemented since 1980's. In watershed management approach, a watershed geomorphology analysis and prioritization for soil and water conservation intervention is widely applied in many countries (3). It is also one of the important aspects to be considered in implementation of any watershed management programmes of which soil and water conservation is the main issue to be considered (4) (5). Watershed is an area of land which contributes runoff to a common point along a single waterway. It is an ideal unit for the management of natural resources and to mitigate the impact of natural disasters (5)(6).

***Corresponding author:* Kossa Terefe Abebe,**
Lecturer, Department of Natural Resources Management, Arsi University College of Agriculture and Environmental Science.

Remote sensing (RS) and Geographical Information System (GIS) plays an important role in the study of a watershed geomorphology, assessing morphometric parameters of a watershed and prioritization for intervention(7)(8). Morphometric analysis is one of the significant models for prioritization of sub-watersheds even in the absence of soil and land use/land cover maps. Watershed prioritization is a ranking of different sub-watersheds/ micro-watersheds based on the order in which they have to be considered for intervention, particularly for soil and water conservation measure(9). It is areas which most likely to contribute a large volume of runoff in a watershed(9). High priority means it becomes potential candidate for applying soil and water conservation measures. Watershed prioritization will be done in various ways. Analysis of linear, shape and relief aspects of a watershed is the most common. Linear parameters include drainage density, stream frequency, bifurcation ratio and texture ratio (10)(11)(12). Shape parameters include compactness coefficient, circulatory ratio, form factor and compactness ratio (10)(12)(13)(14). Relief aspects include watershed relief, relief ratio and ruggedness number (11)(12).

In Ethiopia, watershed management program commenced in a formal way in the 1970s (15). The program was designed to improve upland natural resource management in order to protect downstream resources and infrastructure. A particular concern was to protect a damage caused to downstream infrastructure by degradation of the uplands (16). However, gradually, the government expanded through community-based watershed management as a better option to minimize soil erosion from cultivation land and gained many benefits.
In the study area, Arsi Zone, Oromia Regional State of Ethiopia, runoff generated from uplands has created sever roadside soil erosion and created a great damage to the Adama-Asella main road, which connects the Arsi and Bale Zones-Adama to the capital city of the country, Addis Ababa. More than five kilometers of the asphalt road became out of function. As a result, the traffic from these two Zones to Addis Ababa and the community living vicinity to the road has been affected. The purpose of this study was to investigate runoff contributing watershed to the Adama-Asella road and conduct watershed prioritization for future planning and implementation of soil and water conservation measure.

Objective of the study

To characterize runoff contributing watershed to the Adama-Asella road damage and prioritization of its micro-watershed for watershed management intervention.

MATERIALS AND METHODS

Study area

The study was conducted in Arsi Zone of Oromia Regional State, Ethiopia. The area encompasses parts of the Arsi highlands and the central rift valley. It is located on the main road from Adama-Asella to south east of Addis Ababa, capital city of Ethiopia. The study lies between the coordinates of 8°9′20 to 8°16′30″ N and 39° 12′32″ to 39°18′0″E with an estimated area of 32km^2. Its elevation ranges from 1735 meter to 2303 meter above sea level(Fig 1). Hydrologically the area is a part of the Awash Basin, one of the country's twelve major basins. The mean annual rainfall of the area is 788mm. It has a uni-modal rainfall pattern with extended rainy season from March to September with the peak rainy season is from July to August(17).96.7% of the study area is cultivation land whereas 3.3% is open shrub land(18).The farming system is a mixed agriculture with the dominant crops grown of wheat and teff (19). Most of the volcanic rocks in the study area were formed during the Cenozoic era of the tertiary period because of the wide spread volcanism induced by extensive fracturing and subsequent faulting (17).

Data Base and Methodology: An integration of remote sensing and geographic information system technology was adopted in the study. At first, runoff contributing watersheds to the eroded roadside were delineated with the help of Geographic Information System (GIS 10.4), and Soil and Water Assessment Tool (SWAT 2012.10_522) Interface software from Digital Elevation Model (DEM) obtained from the United States Geological Survey (USGS) Earth Explorer. In addition, Global Position System (GPS) Garmin 62s was used for ground truth control point. All the datasets were brought into the same coordinate system of the Universal Transverse Mercator (UTM) projection 37N in the Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) 10.4software. Using the Ethio-road shape file(18), alignment of the damaged road against the natural runoff flow lines of the watershed was evaluated in the GIS environment. Morphometry of the runoff contributing watershed was done using linear, shape and relief parameters using the formulae suggested by (10)(11)(12)(13)(14)and (20)as described in Table 1.Per the recommendation of(21), high weight was given for high values of linear aspects and relief aspects whereas low weight was given for high value of shape aspects. Finally, watershed prioritization was done by a compound factor, which computed by summing all the ranks of linear parameters, shape parameters and relief parameter and then dividing by the number of parameters. The smallest compound value receives the highest priority for a watershed management while the highest compound value is the least priority. The high priority indicates the need of watershed managementintervention.

RESULTS AND DISCUSSION

Morphometric Analysis: Quantitative analysis of the runoff contributing watershed was performed to assess the drainage networks which contribute runoff to the Adama-Asella road damage and its characteristics.

Road alignment versus runoff channel: Boundary of the runoff contributing watershed to the damaged road and its drainage networks was evaluated against the Adama-Asella road alignment by overlaying on the GIS environment (Fig 2). This helps to analyze comprehensively the vulnerability of a road (25).The study showed that two watersheds contribute runoff to the road, a watershed with outlet 1 (hereafter called Hate watershed) and a watershed with outlet 2 (hereafter call Deya watershed) (Fig2). The main natural drainage line of Deya watershed crosses the road six times. However, the road has neither drainage structure along the roadside norculvert for runoff water crossing. This is one of the main reasons for the runoff scouring the roadside and damage to the road. If good drainage is not guaranteed along roadside and at water crossings, flood waters can be abruptly interrupted and alter the morphological conditions of the channel and create danger on the road structures. In addition, high erodibility characteristic of the sandy dominated soil type of the site made it to easily susceptible for the erosion. Erodibility of sand soil is high (26). Runoff generation from Hate watershed and concentrating at the outlet 1 was also the other major reason for the Adam-Asella roadside erosion and damage. At outlet 1, high runoff generates to the road from upstream. However, there was no adequate culvert for water crossing the road. As a result, much runoff flows along the roadside without road drainage dich. During heavy rain storm, much water generates from the upper watershed, which is clay dominated soil and relatively sloppy area. Clay soil has low infiltration and high runoff generation (27). High slope favor rate of runoff generation and reduce time of concentration (28).

Evaluation and prioritization of the Adam-Asella runoff contributing micro-watersheds: To evaluate geomorphology of the runoff contributing micro-watersheds and prioritization for watershed management implementation, the entire watershed was divided in to two sub-watersheds namely Deya sub-watershed and Hate sub-watershed. Each sub-watershed again subdivided into two micro-watersheds and assigned micro-watershed one (MW1), micro-watershed two (MW2), micro-watershed three (MW3) and micro-watershed four (MW4)as shown in figure 3. Analysis of the micro-watersheds was carried out based on the watershed morphometric characterization parameters of linear, areal and relief ratio per the recommendations of various authors (Table 1). Brief description of the micro-watersheds' linear, areal and relief aspects explained below.

Linear Parameters: Bifurcation ratio (Rb), drainage texture (Dt), stream frequency (Fs), drainage texture ratio (Dt) are linear parameters that were evaluated to prioritize the micro-watersheds. To evaluate these parameters, stream order, stream number, total stream length and mean stream length of each micro-watershed was determined as follow.

Stream order (U): The designation of stream ordering was done according to the hierarchic method of Strahler (1964).Stream order of the micro-watersheds are shown in Table 2.The stream order analysis showed MW3 is a third order stream covering an area of 9.3km^2 whereas MW1, MW2 and MW4 are second order streams covering an area of 8.05km^2, 6.83km^2, and 7.71km^2, respectively. Higher stream order is associated with greater volume of runoff generation (29). The study showed MW3 generates the greatest volume of runoff to the road due to its stream order. The variation in order and size of the tributary of the micro-watersheds is largely due to physiographic of the area.

Total stream Length (L): Total stream length is sum of all streams in the micro-watershed. It is related to the characteristics of surface runoff a watershed (30). High stream length segment indicates flatter gradients and small stream length represents high slope and fine texture (31). Total stream length of each micro-watershed is indicated in Table 2. Total stream length of MW1, MW2, MW3 and MW4 are 23.36 km, 21.12 km. 23.72 km and 18.36 km, respectively.

Mean Stream Length (Lsm): The mean stream length (Lsm) was calculated by dividing the sum of total length of the stream to total number of streams. The mean stream length is directly related to mean annual runoff; the highest mean stream length indicates relatively high mean annual runoff(11). Lsm of the micro-watersheds are shown in Table 2. Lsm of MW1 is the highest of the micro-watersheds and therefore it contributes the highest runoff to the damaged road.

Bifurcation Ratio (Rb): Bifurcation ratio (Rb) is defined as the ratio of the stream segments number of a given order to the segment number of the next higher order (12). Bifurcation ratio shows a small range of variation for different environmental conditions. Rb decreases as order of stream increases (11). Bifurcation ratio varies based on the slope of the terrain, physiography and climatic conditions. It has a relationship with the branching pattern of a stream network. Higher bifurcation ratio represents early hydrograph peak has a potential to create flash flooding during the storm events. The lower value of mean bifurcation ratio shows the geological variation, higher infiltration and less structural control in the watershed (32). Bifurcation ratio, generally, shows value from 3 to 5 in the geologic structures do not affected (11).Though it is said a bifurcation ratio, mean bifrictio ratio is used in the watershed prioritization. Mean bifurcation ratio (Rbm) is calculated as the arithmetic mean bifurcation ratio (33). High Rb values indicate high runoff generation and low infiltration while low Rb values reflects low runoff generation and high infiltration rate (34). Mean of bifurcation of the micro-watersheds are shown in Table 3. Mean of bifurcation ratio of the study micro-watersheds range from 3.5 to 11.The highest mean Rb of MW4 is 11, which indicates the highest runoff generation.

Drainage Texture (Dt): Drainage texture (Dt) is the number of stream segments of all orders per perimeter of the micro-watershed area. It shows the closeness of one stream to another stream (35).Dt of the micro-watersheds are shown in Table 3. Dt of MW1, MW2, MW3 and MW4 are 0.35, 0.55, 0.80 and 0.41, respectively. Dt of MW3 is the highest. High Dt indicate fine texture, which reflects low infiltration and high runoff. This indicates MW3 contributes high runoff to the road while MW1 is the least.

Stream Frequency (Fs): The stream frequency (Fs) is the total number of stream segments of all orders per unit area (10). Fs has a positive correlation with Dd (31). Fs is related to permeability, infiltration capacity, and relief of micro-watershed. respectively. If the stream frequency is higher, it reflects a greater runoff due to steeper slope. Fs of MW1, MW2, MW3 and MW4 are 1.24, 2.20, 1.93 and 1.56. This indicates that MW2 contributes high runoff to the road while MW3 the second in contributing high runoff to the road. On the other hand, MW1 and MW4 contribute less runoff to the road.

Areal Aspects

Area (A) and Perimeter (P): Area of a watershed is directly related to the hydro-graph storm peak and the volume of runoff (36). The perimeter is the total length of the drainage basin boundary (1). Area and perimeter of the study micro-watershed are shown in Table 2.

Form Factor (Ff): Form factor (Ff) is the ratio of the watershed area to the square of the watershed length (10). Ff depicts the flow intensity of a watershed. High value of Ff experiences larger peak flows within a shorter duration while low form factor indicates lower peak flows and longer duration (31). Ff of the micro-watersheds are shown in Table 3. Ff of MW1, MW2, MW3 and MW4 are 0.04, 0.06, 0.10 and 0.04, respectively. Ff of MW3 is the highest of all micro-watersheds. This indicates that highest runoff generation to the road due to its Ff is from MW3.

Compactness constant (Cc): It is the ratio between basin perimeters to the perimeter of a circle to the same area of the watershed. It derives the relationship between actual hydrologic basins to the exact circular basin having the same area as that of hydrologic basin (10). Cc approaches to one means, the micro-watershed is circular and risky of runoff generation is high because it will yield the shortest time of concentration before peak flow occurs in the micro-watershed (37). Cc of the micro-watersheds are shown in Table 3. Cc of MW1, MW2, MW3 and MW4 are 0.12, 0.11, 0.23 and 0.12, respectively. Cc of the MW3 is 0.23, which indicates high risky of runoff generation to the road.

Table 1. Morphometric parameters adopted for computing morphology of the watershed

Morphometric parameter	Formula	Reference
Stream number (Nu)	Number of stream segments	(11)
Stream order (U)	Hierarchical rank	(11)
Total stream length (L)	Sum of all streams in the area	GIS
Mean stream length (Lsm)	Msm = Lu/Nu, Lu = total stream length of order ''u'', Nu = total number of stream segments of order ''u''	(11)
Bifurcation ratio (Rb)	Rb = Nu/Nu-1; Nu = total number of stream segments of order "u"; Nu-1 = number of segments of next higher order	(12)
Mean bifurcation ratio (Rbm)	Average of bifurcation ratios of all orders	(22)
Watershed length (Lb)	The drainage line distance from a basin's mouth to the point on the water divide intersected by the projection of the direction of the line through the source of the main stream.	(10)
Perimeter (P)	The outer boundary that enclosed the area	(24)
Area (A)	The entire area drained by a system of streams	GIS
Drainage density (Dd)	Dd = L/A; L = total stream length of all orders (km); A = area (km^2)	(10)
Stream frequency (Fs)	Fs = Nu/A; Nu = total number of streams of all orders; A = area (km^2)	(10)
Drainage texture (Dt)	Dt = Nu/P;Nu = total number of streams of all orders; P = perimeter (km)	(10)
Form factor (Rf)	$Rf = A/Lb^2$; A = area (km^2); Lb^2 = square of basin length	(10)
Elongation ratio (Re)	$Re = 2/Lb \times (A/\pi)^{0.5}$ Where, A= area of the basin, Lb= basin length (Km)	(12)
Circulatory ratio (Rc)	$Rc = 4\times\pi\times A/P^2$, Where, π= 3.14, A= area of the basin,	(22)
Compactness coefficient (Cc)	$Cc = 0.2821 \times P/A^{0.5}$, P= perimeter of the basin, A= area of the basin	(10)
Basin relief (Bh)	Vertical distance between the lowest and highest points of basin	(12)
Relief ratio (Rh)	Rh = Bh/Lb, where Lb= basin length	(12)

Table 2. Basic parameters of four micro-watersheds of Adama-Asella runoff contributing micro-watersheds

MW	Area(Km^2)	Perimeter(Km)	Lb (Km)	L (Km)	Nu	Lsm (km)	U	Bh
MW1	8.05	28.96	14.31	23.36	10	2.34	2	0.29
MW2	6.83	27.43	10.67	21.12	15	1.41	2	0.3
MW3	9.34	22.41	9.86	23.72	18	1.32	3	0.34
MW4	7.71	28.96	13.73	18.36	12	1.53	2	0.36

Table 3. Linear and aerial morphometric parameters of sub-watersheds

Parameter	Linear aspect				Areal aspect				
MW	MW1	MW2	MW3	MW4	MW	MW1	MW2	MW3	MW4
Rbm	4.00	3.50	3.50	11.00	Ff	0.04	0.06	0.10	0.04
Rank	2	3	3	1	Rank	1	2	3	1
Dd	2.90	3.09	2.54	2.38	Re	0.22	0.28	0.35	0.23
Rank	2	1	3	4	Rank	1	3	3	2
Dt	0.35	0.55	0.80	0.41	Cc	2.88	2.96	2.07	2.94
Rank	4	2	1	3	Rank	2	4	1	3
Fs	1.24	2.20	1.93	1.56	Rc	0.12	0.11	0.23	0.12
Rank	4	1	2	3	Rank	2	3	1	2

Table 4. Relief aspects of the micro-watersheds

MW	Bh	Rh	Rank
MW 1	0.29	0.02	2
MW 2	0.30	0.03	1
MW 3	0.34	0.03	1
MW 4	0.36	0.03	1

Table 5. Prioritization of 4 micro-watersheds contributing runoff to the Adam-Asella road based on morphometric analysis

MW	Rbm	Dd	Dt	Fs	Ff	Rc	Re	Cc	Rh	CP	Final Priority
MW 1	2	2	3	4	1	2	1	2	2	2.11	2
MW 2	3	1	2	1	2	4	3	3	1	2.22	3
MW 3	3	3	1	2	3	1	3	1	1	2.00	1
MW 4	1	4	4	3	1	3	2	2	1	2.33	4

Elongation Ratio (Re): The elongation ratio (Re) is the ratio of the diameter of a circle which has the same area with the watershed area to the watershed length (Lb) (12). Re close to 1 shows very low relief whereas 0.6to 0.8 is high relief and moderate to steep ground slope (11). Based on Re shape of the watershed can be described as circular for Re> 0.9, oval for Re of 0.9 to 0.8 and elongated for Re < 0.7(30). Re of the micro-watersheds are shown in Table 3. Re of MW1, MW2, MW3 and MW4 are 0.22, 0.28, 0.35 and 0.23, respectively. Re of MW3 is the highest. This indicates the highest runoff generation is contributed from it to the road due to its Re while MW2 contributes the second higher runoff generation.

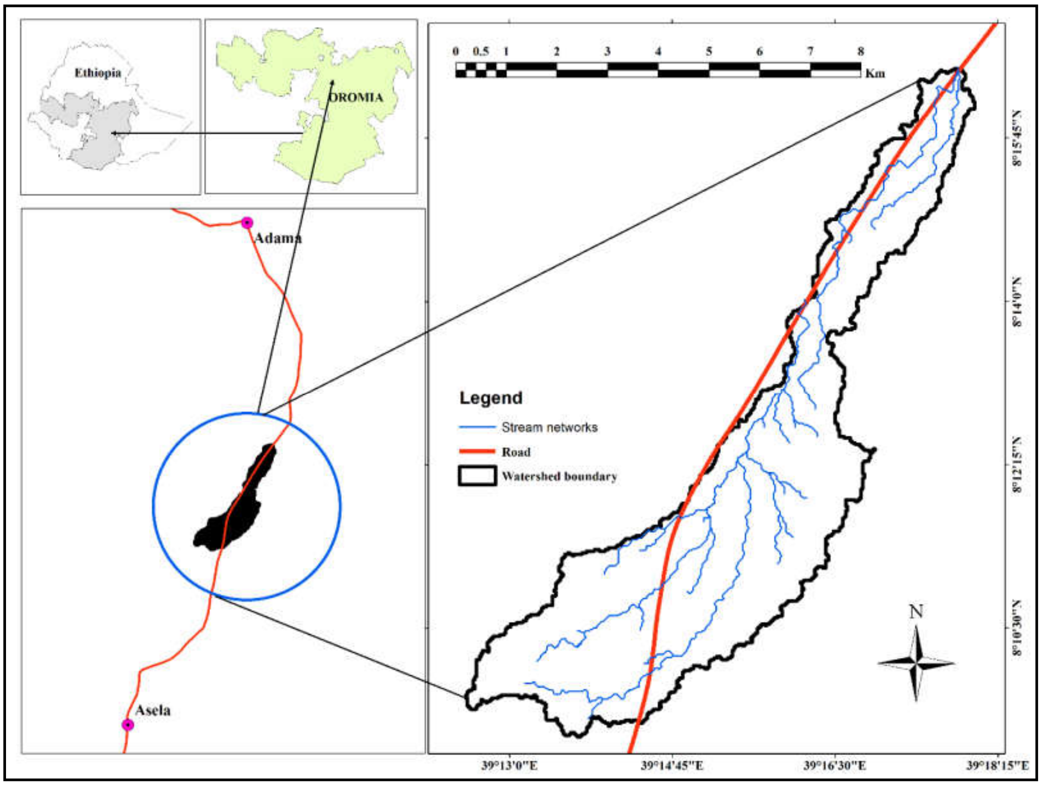

Figure 1: Runoff contributing watershed to Adama-Asella Road

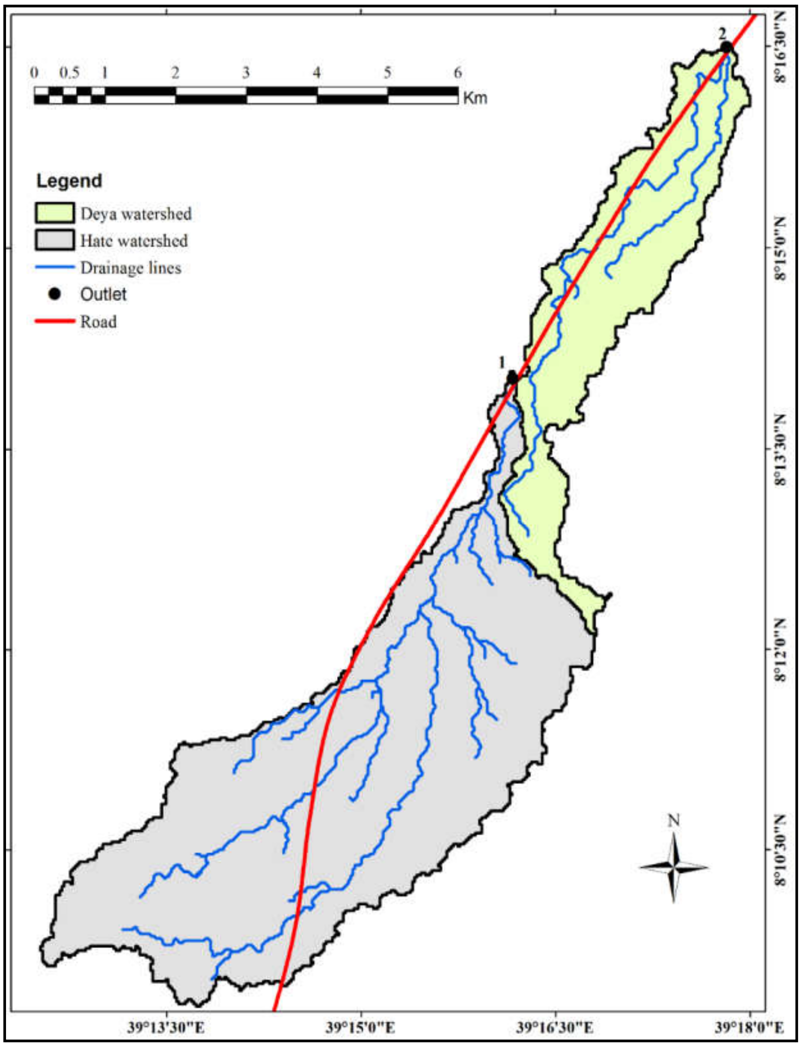

Figure 2: Overlay of runoff contributing watershed to the Adama-Asella roadside soil erosion and the road

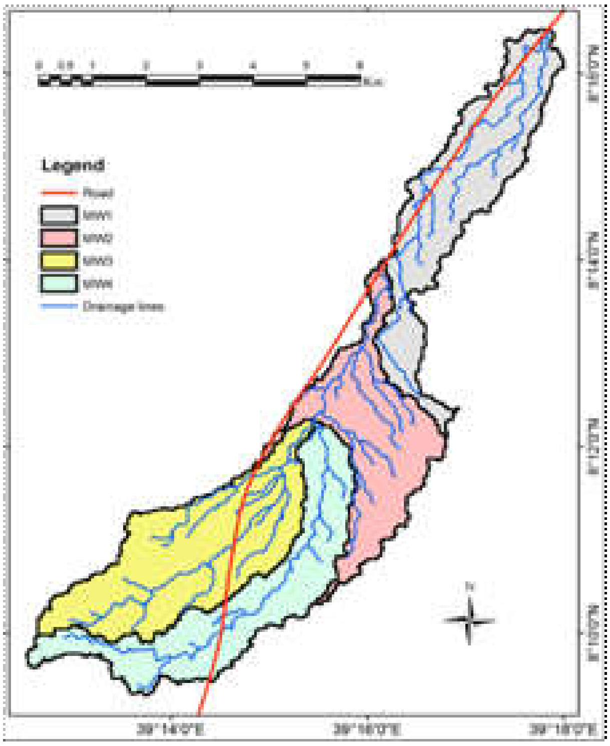

Figure 3: Micro-watersheds contributing runoff to the Adam-Asella damaged road

MW1 and MW4 contributes similar and lower runoff to the road due to their Re.

Circulatory Ratio (Rc): The circulatory ratio (Rc) can be interpreted as the capacity of watershed to drain out water (38). Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (39). Rc of the micro-watersheds are shown in Table 3. Rc of MW1, MW2, MW3 and MW4 is 0.12, 0.11, 0.23 and 0.12, respectively. Rc of MW3 is the highest while in the other micro-watershed more or less similar. This indicates MW3 contributes the highest runoff generation to the road due to its Rc while in the rest of micro-watersheds the effect of Rc is similar.

Relief Aspect

Basin Relief (Bh): Basin relief (Bh) is the elevation difference between head of the watershed and the outlet (29). Bh helps to understand the geomorphic process and characteristics of landform of the watershed and influence the surface runoff (40).

Relief Ratio (Rh): The relief ratio (Rh) increases with decreasing watershed area. The highest value of Rh shows steep slope while the lower Rh indicates lower slope(41).Relief ratio of the micro-watersheds are showmen in Table 4. Rh of MW2, MW3 and MW4 is 0.03 while Rh of MW1 is 0.02. This indicates the effects of Rh on runoff generation to the road in MW2, MW3 and MW4 are similar while in the MW1 is lower.

Prioritization of Micro-Watersheds: Prioritization of all micro-watersheds of the Adama-Asella runoff contributing micro-watershed was carried out by calculating the compound morphometric parameter values based on the morphometric analysis. Table 5 shows analysis of the results of watershed prioritization assessment. The results of the analysis reveal that compound value of micro-watersheds MW3 is the lowest while compound value of MW4 is the highest. This indicates MW3 is the highest priority micro-watershed while MW3 is the least priority micro-watershed. The second and third priority micro-watershed are MW1 and MW2, respectively.

Conclusion

Prioritization of the micro-watersheds is one of the important aspects of watershed management planning. The study demonstrated the usefulness of RS & GIS for conducting runoff contributing watershed to the Adama-Asella road, analysis of its morphometry as well as prioritization of the micro-watershed for future intervention. Morphometric characteristics of the micro-watersheds show their relative characteristics with respect to runoff contribution and required for implementation of soil and water conservation. Prioritization of the four micro-watersheds reveals that micro-watershed MW3 is the highest priority hence may be taken for first conservation measures decision makers while MW1, MW2 and MW4 are the second, third and fourth priority, respectively.

Acknowledgement

I would like to thank Arsi University and Hetosa Agriculture Office for their support in conducting this reach.

Conflict of interest: The paper has not been previously published and it is not under publication elsewhere

Funding: This research is funded by Arsi University

Glossary of Abbreviations

ArcGIS- Aeronautical Reconnaissance Coverage Geographic Information System
AArea
Bh- Basin relief
Cc- Compactness coefficient
Dd- Drainage density
DEM- Digital Elevation Model
Dt- Drainage texture
Fs- Stream frequency
GIS- Remote sensing
GPS- Global Position System
L- Total stream length
Lb- Watershed length
Lsm- Mean stream length
MW1- Micro-watershed one
MW2- Micro-watershed two
MW3- Micro-watershed three
MW4- Micro-watershed four
Nu - Stream number
P- Perimeter
Rb- Bifurcation ratio
Rbm- Mean bifurcation ratio
Rc- Circulatory ratio
Re- Elongation ratio
Rf- Form factor
Rh- Reliefratio
RS- Geographical Information System
SWAT- Soil and Water Assessment Tool

U- Stream order
USGS- United States Geological Survey
UTM-Universal Transverse Mercator

REFERENCES

1. Das D. Identification of Erosion Prone Areas by Morphometric Analysis Using GIS Identification of Erosion Prone Areas by Morphometric Analysis Using GIS. 2016;(July).
2. Den Biggelaar C, Lal R, Wiebe K, Eswaran H, Breneman V, Reich P. The Global Impact Of Soil Erosion On Productivity*. II: Effects On Crop Yields And Production Over Time. Adv Agron. 2003;81(03):49–95.
3. Alkharabsheh MM, Alexandridis TK, Bilas G, Misopolinos N, Silleos N. Impact of Land Cover Change on Soil Erosion Hazard in Northern Jordan Using Remote Sensing and GIS. Procedia Environ Sci [Internet]. 2013;19:912–21. Available from: http://dx.doi.org/10.1016/j.proenv.2013.06.101
4. Kushwaha NL, Characterization H, Erosion S, Mapping R, Watershed OFA, Remote U. Remote Sensing and GIS based Morphometric Analysis for Micro-watershed Prioritization in Takarla-Ballowal Watershed. 2020;(January).
5. Said A, Sehlke G, Stevens DK, Glover T, Sorensen D. Exploring an innovative watershed management approach: From feasibility to sustainability. 2006;31:2373–86.
6. Ali U, Ali SA, Ali U. Analysis of Drainage Morphometry and Watershed Prioritization of Romushi - Sasar Catchment , Kashmir Valley , India using Remote Sensing and GIS Technology . 2014;2(12):5–23.
7. Khan MA, Gupta VP, Moharana PC. Watershed prioritization using remote sensing and geographical information system : a case study from Guhiya , India. 2001;465–75.
8. Pandey A, Behra S, Pandey RP, Singh RP. Application of GIS for Watershed Prioritization and Management: A Case Study. Int J Environ Sci Dev Monit. 2011;2(1):25–42.
9. Gajbhiye S, Mishra SK, Pandey A. Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective. Appl Water Sci. 2014;4(1):51–61.
10. Horton. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. Bulletin of the Geological Society of America 56, 2 75-370. Prog Phys Geogr. 1945;19(4):533–54.
11. Strahler AN. Strahler, A. N., 1964. Quantitative geomorphology of drainage basins and channel networks. In Chow, V.T. (ed.) Handbook of Applied Hydrology, McGraw-Hill, New York. pp 439-476. 1964;1964. Available from: http://www.sciepub.com/reference/149079
12. Schumm SA. Geological Society of America Bulletin EVOLUTION OF DRAINAGE SYSTEMS AND SLOPES IN BADLANDS AT PERTH AMBOY , NEW JERSEY. Geol Soc Am Bull [Internet]. 1956;67(5):597–646. Available from: https://pubs.geoscienceworld.org/gsabulletin/article/67/5/597-646/4811
13. Miller VC. A quantitative geomorphic study of drainage basin characteristic in the clinch, Mountain area, Verdinia and Tennesser, Project NR 389-042,Tech. Rept.3 Columbia University, Department of Geology, ONR, Geography Branch, New York. 1953;(389):1953.
14. Umrikar BN. Morphometric analysis of Andhale watershed, Taluka Mulshi, District Pune, India. Appl Water Sci. 2017;7(5):2231–43.
15. Gebregziabher G, Abera DA, Gebresamuel G, Giordano M, Langan S. An assessment of integrated watershed management in Ethiopia. Vol. 170, IWMI Working Papers. 2016.
16. Darghouth S, Ward C, Gambarelli G, Styger E, Roux J, Bank TW. Watershed Management Approaches , Policies , and Operations : Lessons for Scaling Up. 2008;(11).
17. Sahlemedhin Sertsu, Abayneh Esayas DT. The Federal Democratic Republic of Ethiopia: Selected Issues. Vol. 08, IMF Staff Country Reports. 2008.
18. Https://mapcruzin.com/free-ethiopia-arcgis-maps-shapefiles.htm. Ethio-shape file.pdf.
19. Seyoum Taffesse A, Dorosh P, Gemessa SA. Crop production in Ethiopia: Regional patterns and trends. Food Agric Ethiop Prog Policy Challenges. 2013;9780812208:53–83.
20. Sreedevi PD, Subrahmanyam K, Ahmed S. The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. Environ Geol. 2005;47(3):412–20.
21. Nooka Ratnam K, Srivastava YK, Venkateswara Rao V, Amminedu E, Murthy KSR. Check Dam positioning by prioritization micro-watersheds using SYI model and morphometric analysis - remote sensing and GIS perspective. J Indian Soc Remote Sens. 2005;33(1):25–38.
22. Strahler. Quantitative analysis of watershed geomorphology. Am Geophys Union Trans 38:912 – 920. 1957;1957.
24. Zavoianu. Morphometry of drainage basins. Morphometry Drain basins. 1987;94:1987.
25. Li X, Wang W, Li F, Deng X. GIS based map overlay method for comprehensive assessment of road environmental impact. Transp Res Part D Transp Environ. 1999;4(3):147–58.
26. Wlschmeier WH, Mannering J V. DIVISION S-6 — SOIL AND WATER MANAGEMENT. (15).
27. Study C, Retention SW, Techniques I, North T, Piedmont C, Estes CJ. Storm Water Infiltration in Clay Soils : 2007;159–70.
28. Li FH, Wang AP, Wu LS. Interaction effects of polyacrylamide application rate, molecular weight, and slope gradient on runoff and soil loss under sprinkler irrigation. Adv Mater Res. 2014;955–959:3489–98.
29. Al-Saady YI, Al-Suhail QA, Al-Tawash BS, Othman AA. Drainage network extraction and morphometric analysis using remote sensing and GIS mapping techniques (Lesser Zab River Basin, Iraq and Iran). Environ Earth Sci. 1952;75(18).
30. Arulbalaji P, Gurugnanam B. Geospatial tool-based morphometric analysis using SRTM data in Sarabanga Watershed, Cauvery River, Salem district, Tamil Nadu, India. Appl Water Sci. 2017;7(7):3875–83.
31. Waikar ML, Nilawar AP. Morphometric Analysis of a Drainage Basin Using Geographical Information System : A Case study. Int J Multidiscip Curr Res. 2014;2(2014):179–84.
32. Aadil Hamid RAH. Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-

Spatial Technology –A Case Study of Vishav Drainage Basin. J Waste Water Treat Anal. 2013;04(03).
33. Strahler. Quantitative classification of watershed geomorphology. Trans Am Geophys Union. 1957;
34. Thomas J, Joseph S, Thrivikramji KP, Abe G, Kannan N. Morphometrical analysis of two tropical mountain river basins of contrasting environmental settings, the southern Western Ghats, India. Environ Earth Sci. 2012;66(8):2353–66.
35. Smith. Standards for grading texture of erosional topography. Vol. 248, American Journal of Science. 1950. p. 655–68.
36. Ahmed SA, Chandrashekarappa KN, Raj SK, Nischitha V, Kavitha G. Evaluation of morphometric parameters derived from ASTER and SRTM DEM - A study on Bandihole sub-watershed basin in Karnataka. J Indian Soc Remote Sens. 2010;38(2):227–38.
37. Iqbal M, Sajjad H, Bhat FA. Morphometric Analysis of Shaliganga Sub Catchment , Kashmir Valley , India Using Geographical Information System. 2013;(January).
38. Kusre BC. Morphometric analysis of Diyung watershed in northeast India using GIS technique for flood management. J Geol Soc India. 2016;87(3):361–9.
39. Miller. A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. V. C. Miller. J Geol. 1957;65(1):112–3.
40. Choudhari PP, Nigam GK, Singh SK, Thakur S. Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. Geol Ecol Landscapes [Internet]. 2018;2(4):256–67. Available from: http://doi.org/10.1080/24749508.2018.1452482
41. Avinash K, Jayappa KS, Deepika B. Prioritization ofsub-basins based on geomorphology and morphometricanalysis using remote sensing and geographic informationsystem (GIS) techniques. Geocarto Int. 2011;26(7):569–92.

****