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Morphometric Analysis of Watersheds of Thalisain Area Himalaya for Assessing Their Fluvial Erosion Susceptibility Using Geomatic Techniques

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Abstract:
To assess the fluvial erosion susceptibility of watersheds Drainage Morpometric analysis was carried out in Thalisain region of Pauri district, Uttarakhand in India. The SOI toposheet and ASTER DEM were made in use for preparation of drainage and watershed boundary. All the Morphometric parameters related to linear, aerial and relief, drainage gemorphometry was calculated for all the watershed and weightages were allotted to them to drive Composite Weightage Value (CWV). Consequently, by grouping these calculated values of the watersheds were categorized in to four classes such as low, moderate, high and very high watersheds erosion susceptibility. The correlation of CWV with morphometric parameters showed that the high stream frequency, coarser texture, high relief and low length of overland flow control the drainage pattern in the region. It was also observed that among land use/ land cover, agriculture land is major factor governing soil erosion. Geologically, it is influenced mainly by the Quaternary Alluvium and unconsolidated rock formations of the terrain. It was revealed that 4.53% area is prone to low erosion, 33.49 % is prone to high erosion, 22.79% is prone to medium erosion, and 39.20% area is prone to very high erosion. Therefore the study suggests that the soil and water conservation measures are required in the watersheds to control the fluvial erosion.

Keywords: *Watershed, Drainage morphometry, Composite Weightage Value, Soil erosion, Fluvial erosion susceptibility and GIS*

1. Introduction

The watershed is a natural hydrological unit of land, which collects water and drains it though a common point by a system of streams (Paranjape et al.1998). It also acts as a natural water divide that separates one drainage basin from other (Soliman et al. 1998). Hence it is considered as an ideal unit of planning for sustainable development and management of natural resources. Drainage morphometry is measurement and mathematical analysis of configuration of surface, shape and dimensions of its landforms (Clarke 1996: Malik et al. 2011). It is dependent upon physiography of a region and can be used to assess possibilities of soil erosion in a watershed (Chorley 1969; Abrahams 1984). This techniques is simple as compared to other methods of assessing soil erosion of a watershed, such as Modified Universal Soil Loss Equation (MUSLE) (Wischmeier & Smith 1978; Renard et al. 1997), Sediment Yield Index (Neil & Mazari 1993; Ludwig & probst 1998; Lu et al. 2003), etc., because for this analysis only drainage and elevation related information are sufficient.

The Himalayan region owing to its undulating and rugged terrains is subject to runoff water and thus is prone to soil erosion. It has been estimated that the total degraded land, 79% is under water erosion in the river catchments in Himalayan region (Sharma 2008). Therefore about 49% of catchments of its perennial, loss of biodiversity, increased sedimentation of reservoirs, drying up of water resources, recurring flash floods and deteriorating environment (Sharma et al. 2008). The divers of nature forest, soil, climate and uneven complex terrains of the thalisain area, Pauri district of Uttarakhand have made this Himalayan region also an ideal terrain for such soil erosion. In this situation, delineation of erosion susceptible area is necessary for its effective conservation planning (Yadav & Sidhu 2010). Therefore, in the above backdrop the present study was conducted in eleven watersheds of Thalisain Area for assessing its vulnerability due to soil erosion using drainage morphometric analysis techniques. Factors that influences watershed operation:

- The size of watershed increases when both run-off volume and rate increases, whereas both rate and volume per unit of watershed are decreases as the area decreases. The size plays an important role in determining the peak rate of run-off.

- Long and narrow watersheds have longer time of concentration resulting in lower runoff- rates than more square watersheds of similar size, which have a number of tributaries discharging into the main channel. This type of concentration also affects the amount of water infiltration into the soil in the watershed. The longer time it takes to leave the watershed, the greater is its seepage into the soil.
- Slope has most important inferences on land-use. The speed and extent of run-off depend on the slope of the land. Higher is the slope, the velocity increases and run-off also increases. The degree of slope sets limits on land use for annual crops, plantation and land reclamation, depending on soil depth.
- The pattern of drainage all depends on the course of the stream and their tributaries. The factor which influences the drainage pattern are land slope, lithology and structure. Coarser the drainage texture, higher is the conductivity and finer drainage texture results in heavier soil type. Here drainage patterns act as guideline to locate vulnerable areas requiring different kinds and degrees of soil conservation measures.
- Soil also determines the amount of silt that will be washed down into water harvesting structure.
- The type of vegetation cover influences the run-off, infiltration rates, erosion, sediment production and evapotranspiration rate. Dense vegetation reduces erosion.
- Rainfall distribution also affects the area as evenly rain throughout the year has a different impact than a sudden sharp seasonal rainfall.

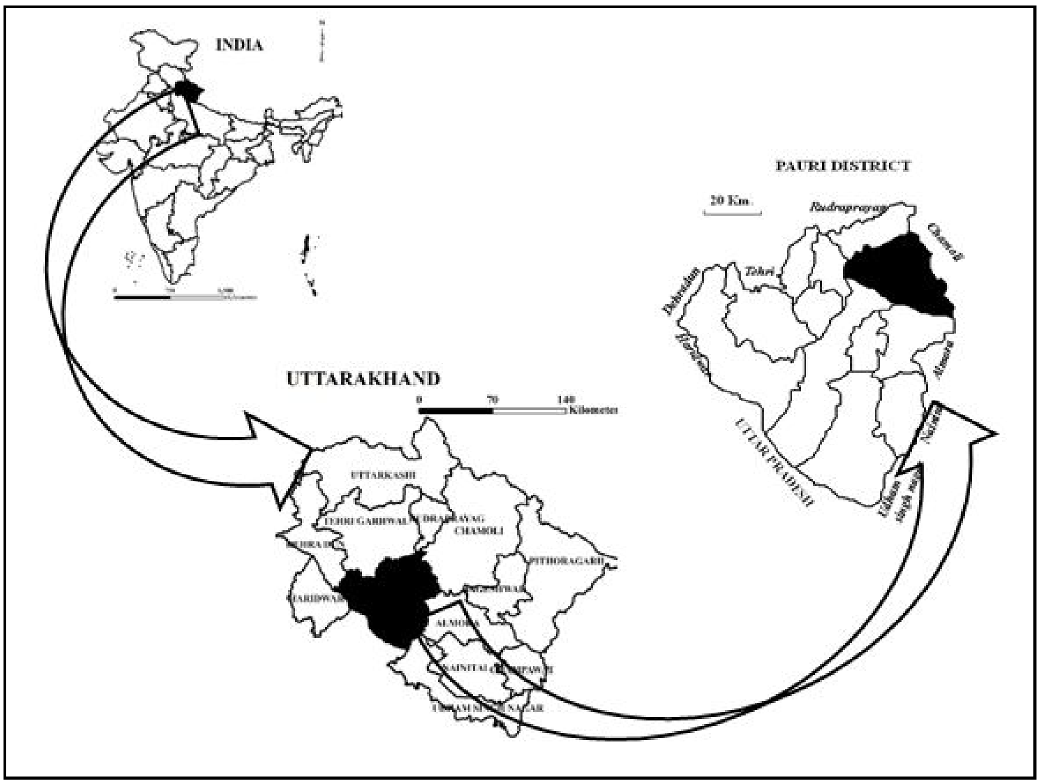

Figure 1: Location map

2. Geoidentity

Thalisain area of Pauri district is the area of interest and is extended from 29°54’30” to 30°10’0” N and 78°54’0” to 79°13’30” E, measuring 35km in length and 49km in width and covers 584 km^2 (Fig. 1), The Eastern part is delineated with an alpine pasture locally known as Bugyal is Dudhatoli ridge. The trunk Channels of Eastern and Western Nayar and Bino River comes from Dhudhatoli ranges, flows in different lithotectonic conditions which can be observed in area platform geometry and its drainage development pattern. The Thalisain block is, located in the lesser Garhwal Himalaya south of the Dudhatoli range, and exhibits a variety of Meta sediments that have suffered multiple phases of, deformation and metamorphism (Gairola and Joshi, 1978). The Lesser Himalaya is formed of Sedimentary, low grade metamorphic and igneous rocks. Middlemiss (1837) was the first to carry out investigations regarding the geology of the Dudhatoli range. Auden (1937) described the Dudhatoli crystallines as a thrust sheet. Later (1949) he thought the Dudhatoli granites and schists to be occurring at the base of the Krol Nappe unit.

The Dudhatoli granite massif is extended in the north west of Almora Crystalline Thrust sheet (Gansser, 1964). According to this study a total of 11different order sub basins of thalisain area transverse to different litho-tectonic setting are identified for detailed analysis of linear morphometric parameters. Structurally, the study area which forms a part of the Dudhatoli Almora Thrust sheet (Gansser 1964), is very interesting where linear and planer structures and folds are very well developed. The important rocks types present in the study area are Granite, Schists, Quartzites and Gneisses (Fig. 2).

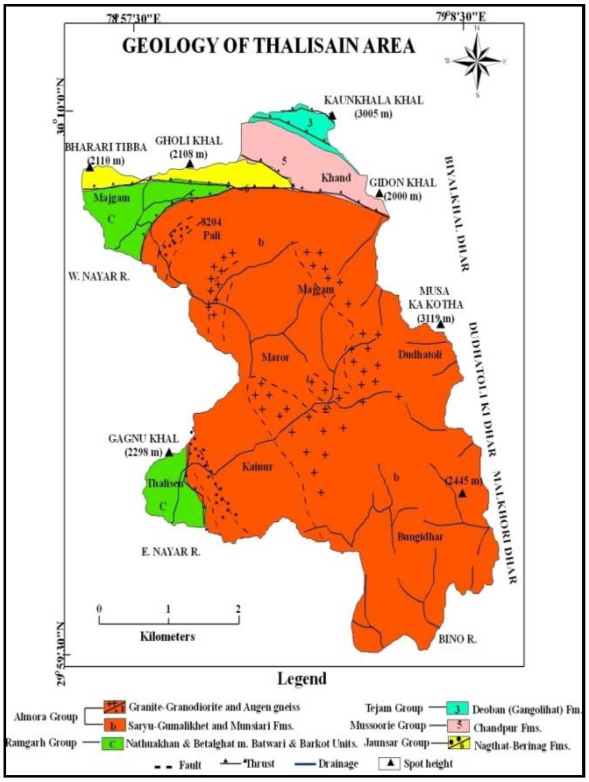

Figure 2: Geological map

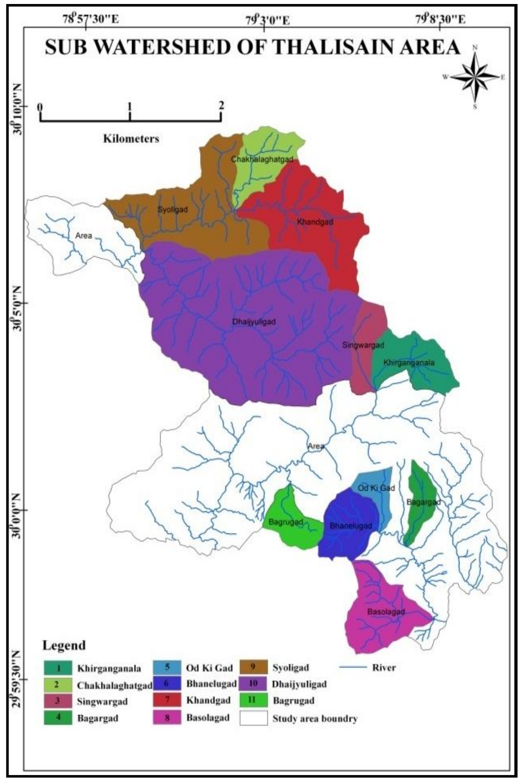

Figure 3: Sub watershed map of Thalisain area

2.1. Drainage Pattern

The major drainage patterns in the study area are dendritic observed mostly in Dhijyuli gad and its tributaries (western nayar), masangari nadi tributary of bino and tributary of eastern nayar like bagru gad.Radial in the north (Sountkhaldhar), south (Bangarsain, Kalijabar and Ranot dhar) and east (Malkhari, Dudhatoli and Biyakhaldhar) and localities of Eastern-Western and Bino basin. Faulted, Parallel and Trellis are the other drainage pattern present in the area.

2.2. Landuse/Landcover

The landuse/landcover map prepared using IRS ID LISS III satellite image depicts presence of five classes in the study area. Broadly, the land utilization pattern of the study area has been grouped into five categories (i) agricultural populated flat land, (ii) barren land, (iii) sparsely vegetated forest area with lesser ground cover, (iv)moderately vegetated forest area and (v) thickly vegetated forest area. The 3.51 % of the area fall under sparsely vegetated forest area, followed by waste land 10.22%, moderately vegetated forest area 17.60%, agricultural and populated flat land 18.54 %, and Thickly forest area 50.13%.

3. Material and Methodology

The topographical map on 1:50,000 Scale form Survey of India (no.53J/16, 53K/13, 53N/4 and 53O/1) covering study area were scanned and geo-referenced so as to get geographical coordinates. The drainage network depicted on the georeferenced maps was digitized using Arc GIS software into ESRI shape format (Kumar et al. 2014). The typology of shape files of drainage was built using Arc GIS 10. The watershed boundaries were generated using ASTER digital elevation Model in tiff format. The codification of watershed was done following alphanumeric codification system (AIS & LUP 1990).The ordering of the drainage was done using Strahler system of 'Stream ordering' (Strahler 1964).

The linear, aerial and relief morphometric parameters were derived for all the watersheds. Among these parameters, smaller 'Stream length (Lu)' are characteristic of larger slopes and finer textures while longer length of streams are indicative of flatter gradients. 'Mean Stream length (Lum)' is related to drainage network components and its associated basin surfaces. The 'Bifurcation Ratio (Rb)' generally ranges between 3 and 5 for basins where geological structures do not distort the drainage pattern. A high 'drainage density (D)' occur in the region of dissected topography. The drainage density < 2 indicates very coarser, 2 to 4 is related to coarser, 4 to 6 is moderate, between 6 and 8 is fine and > 8 result in very fine drainage texture. The 'Form Factor (Rf)' generally varies from 0.16 to 0.99. Smaller the value of form factor, more elongated will be the basin. It will always be greater than 0.78 for a perfectly circular basin. The 'Circularity Ratio (Rc)' of 0.4 to 0.5 indicates strongly elongated and homogeneous geologic formations. 'Elongation Ratio (Rc)' generally ranges from 0.6 to 1.0 over a wide variety of climatic and geologic conditions. The higher value of 'Length of over land flow (Lg)' indicates low relief and vice versa. The 'Compactness Coefficient (Cc)' determines shape of the drainage basin. If a basin is a perfect circle then Cc would be equal to 1. The 'relief ratio (Rh)' normally increased with decreasing drainage basin. The high 'Ruggedness number (Rn)' of watershed implies that area is more prone to soil erosion. The 'area of the basin (A)' directly affects the size of the storm hydrograph.

The different values obtained for morphometric parameters were grouped into four classes in increasing order following quartile statistical techniques. Thus, the class 4 represents the set of highest values and class 1 represented set of lowest values. The weightage were assigned to these classes in the order of 1 to 4 when morphometric parameters positively affect watershed erosion. In case where parameters negatively influence the watershed erosion, weightage were assigned in reverse order such as 4 to 1. After weightage assignments, the shape file of above parameters were converted in to ESRI grid formats. These grids were then added using 'add grid' spatial analyst function in Arc View 3.3 to get composite weightage values (CWV) for watersheds. These CWV were again grouped into four classes. The class 1 thus produced had set of lowest CWV and it represented area which is less prone to erosion. Similarly, class 2, 3 and 4 represented area with medium, high and very high watershed erosion susceptibility (Fig. 4). Finally, the CWV for watersheds was statistically correlated with morphological parameters, land use/ land cover and rock types of the watersheds (Kumar et al. 2014).

4. Result and Discussion

The drainage morphometric analysis revealed that the total number of streams in the study area is 3495 where the highest order of stream was up to 6. The first order drainage are 2698 with are approximately four times of second order stream which are 613 in numbers. From all the watersheds, watershed no. 10 has sixth order,

- Wno.1:It is drained by the Khirganga River. It is the sixth largest in terms of size and sixth in terms of drainage density with 136 streams. The highest order of drainage was observed up to fourth. The remarkable change in stream length ratio from 1.66 to 3.75 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the form factor (0.30), circularity ratio (0.56), elongated ratio (1.45) and relative relief (405) and ruggedness number (3.19). It indicates near to circular nature of watershed leading to flooding during peak flow. Besides this the mean bifurcation ratio (4.62) and 100% forest area is the reason for this watershed is less susceptible watershed.
- Wno.2:It is drained by the Chakhaaghat River. It is the seventh largest in terms of size and sixth in terms of drainage density with 82 streams with drainage frequency is (3.05). The highest order of drainage was observed up to fourth. The remarkable change in stream length ratio from 2.00 to 0.24 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the form factor (0.72), circularity ratio (0.72), elongated ratio (1.86) and relative relief (467) and ruggedness number (2.63). It indicates circular nature of watershed leading to flooding during peak flow. Besides this the mean bifurcation ratio (4.25) resulted due to its 28.17% agricultural, no barren land and 71.81% forest areas are the major cause of erosion in this watershed making it the moderate susceptible watershed.
- Wno.3:It is drained by the Singwar River. It is the fourth largest in terms of size and fifth in terms of drainage density with 73 streams and drainage frequency is 2.35. The highest order of drainage was observed up to third. The remarkable change in stream length ratio from 0.92 to 0.22 indicated variation in slope and topography from 2nd to 3rdorder stream. Though the watershed formation consisting of granites, gneiss, schists, quartzite but the area has 100% forest area. This watershed has the form factor (0.27), circularity ratio (0.55), elongated ratio (1.07) and relative relief(448) and ruggedness number (1.23). It indicates elongated nature of watershed leading to less flooding but flooding will be during peak flow. Besides this the mean bifurcation ratio (6.62), the area is cause of less erosion in this watershed making it the moderate susceptible watershed.
- Wno.4:It is drained by the Bagar Ki Gad. It is the second smallest in terms of size and tenth in terms of drainage density with 32 streams. The highest order of drainage was observed up to fourth. The remarkable change in the stream length ratio from 1.10 to 0.25 indicated variation in slope and topography from 2nd to 3rd order stream. This watershed has the form factor (0.25), circularity ratio (0.56), elongated ratio (0.87) suggested that the shape of watershed as circular in nature making it favorable for flooding, relative relief (458) and ruggedness number (1.16). It indicates circular nature of watershed leading to flooding during peak flow. Besides this the highest mean bifurcation ratio (3.15) resulted due to its 48.28% agricultural area, 11.17%barren land and 40.55% forest are the major cause of less erosion in this watershed making it the least susceptible watershed.
- Wno.5: It is drained by the Od ki Gad. It is the smallest in terms of size and eleventh in terms of drainage density with 39 streams. The highest order of drainage was observed up to fourth. The remarkable change in stream length ratio from 3.00 to 0.19 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the form factor (0.35), circularity ratio (0.60), elongated ratio (0.94) and highest relative relief (612) restrict the probability of flooding. It indicates circular nature of watershed leading to flooding during peak flow. The terrain's underlain rocks are Quartzite, gneiss and ruggedness number (1.35). Drainage texture is lowest (1.25) and overland flow is (0.60). Besides this the highest mean bifurcation ratio (4.9) resulted due to its 5.79% agricultural area, 12.15% barren area and 82.06% forested area are the major cause of erosion in this watershed making it the less susceptible watershed.

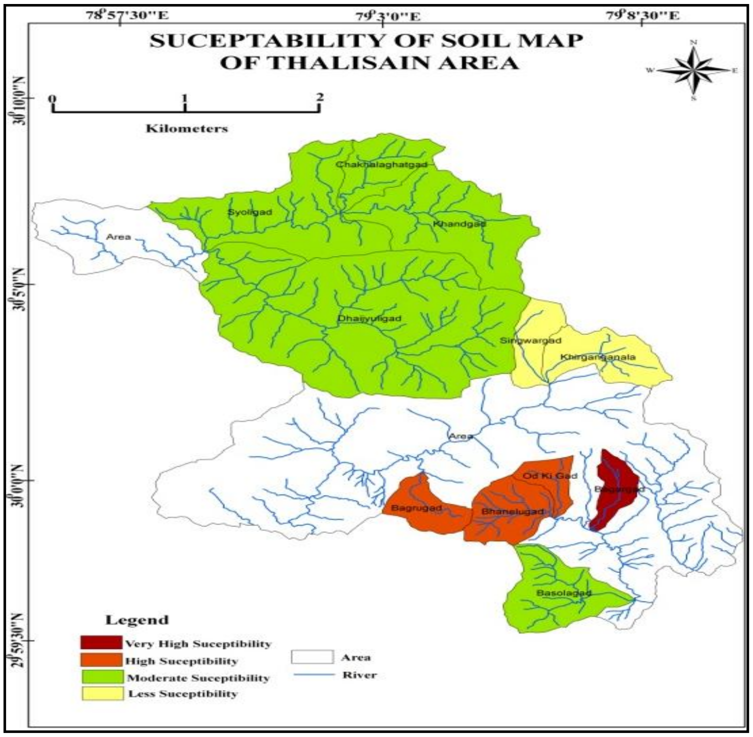

Figure 4: Sub watershed map of Thalisain area

- Wno.6: It is drained by the Bhanelu River. It is the seventh largest in terms of size and fourth in terms of drainage density with 19 streams. The highest order of drainage was observed up to fourth. The remarkable change in stream length ratio from 1.60 to 0.46 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the highest form factor (0.73), circularity ratio (0.88), elongated ratio (2.09) and relative relief (533) and ruggedness number (2.9). It indicates circular nature of watershed leading to flooding during peak flow. Besides this the highest mean bifurcation ratio (2.06) resulted due to its 45.8% homogenous alluvium surface and 44.9% agricultural area are the major cause of erosion in this watershed making it the moderate susceptible watershed.
- Wno.7: It is drained by the Khand River. It is the ninth largest in terms of size and tenth in terms of drainage density with 281 streams. The highest order of drainage was observed up to fifth. The remarkable change in stream length ratio from 1.43 to 0.34 indicated variation in slope and topography from 4th to 5th order stream. This watershed has the lowest form factor (0.18) and elongated ratio (1.65) result in elongated shape of watershed and there is risk of erosion. Here circularity ratio (0.49), relative relief (193), ruggedness number (8.25) and mean bifurcation ratio (4.47) resulted due to its 28.17% agricultural area, no barren land and 91.4 % forest. Due to less circulatory, relief ratio and form factor watershed is slightly elongated shape, these are the reason for erosion.
- Wno.8: It is drained by the Khand River. It is the eighth largest in terms of size and seventh in terms of drainage density with 106 streams. The highest order of drainage was observed up to fifth. The remarkable change in the stream length ratio from 1.00 to 0.34 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the form factor (0.33), circularity ratio (0.84), elongated ratio (1.68) and relative relief (285) and ruggedness number (4.65). Besides this the highest mean bifurcation ratio (3.64),45.33% agricultural area, highest barren land 37.33% and forest 17.33% These are a major cause of erosion in this watershed making it the second most susceptible watershed.
- Wno.9: It is drained by the Syoli River with tenth largest in terms of size and ninth in terms of drainage density with 151streams. Fifth is the highest order of drainage and stream length ratio varies from 0.78 to 0.42 indicated variation in slope and topography from 2nd to 3rd order stream. This watershed has the second lowest form factor (0.23), it has least probability of flood hazard due to its lowest circularity ratio (0.44), elongated ratio (2.01) and relative relief (213) and ruggedness number (9.15). Besides this the highest mean bifurcation ratio (2.62) these are the factor which makes this watershed susceptible for erosion.
- Wno.10: It is drained by the Dhaijyuli River. It is the eleventh largest in terms of size and eleventh in terms of drainage density with 1068 streams. The highest order of drainage was observed up to sixth. The remarkable change the stream length ratio from 5.00 to 0.30 indicated variation in slope and topography from 5thto 6th order stream. The 34.9% of the agricultural, it consists 28.36% barren land and 36.74 % forest. This has led to highest drainage density (25.05), Drainage frequency (24.05) and drainage texture (23.61) which gives more number of closely spaced streams. The result of coarse texture and dissected topography is that it will make watershed most susceptible to erosion among all the watershed. This watershed has the form factor (0.30), circularity ratio (0.74), elongated ratio (3.45) which indicates non circular nature of watershed, lowest relative relief (133) and highest ruggedness number (22.75). Besides this the highest mean bifurcation ratio (4.52) these are major cause of erosion in this watershed making it the first most susceptible watershed.

- Wno.11: It is drained by the Bagru River. It is the ninth largest in terms of size and fourth in terms of drainage density with 63 streams. The highest order of drainage was observed up to fourth. The remarkable change in stream length ratio, from 1.60 to 0.26 indicated variation in slope and topography from 3rd to 4th order stream. This watershed has the form factor (1.10), circularity ratio (0.71), elongated ratio (1.10) and relative relief (436) and ruggedness number (2.15). It indicates the circular nature of watershed leading to flooding during peak flow. Besides this the highest mean bifurcation ratio (3.24) resulted due to its 45.8% homogenous alluvium surface and 44.9% agricultural area are the major cause of erosion in this watershed making it the moderate susceptible watershed.

The statistical analyses reflected that among all the parameters, drainage texture (Y=0.24),drainage order (Y=0.14), area (Y=0.23), stream number (Y=0.17), stream length (Y=0.18), weighted mean bifurcation ratio (Y=0.17), circulatory ratio (0.03), elongated ratio (Y=0.16), form factor (Y=0.04), drainage density (Y=0.23), dissection Index (Y=0.24)and total stream frequency (Y=0.23) showed positive correlation, while length of overland flow (-0.03), relief (Y=-0.24) were negatively correlated with CWV of susceptibility of soil erosion. The positive correlation was observed between CWV and agriculture is (0.78). It was negatively correlated with Forest land (-0.91) and slopes (-0.98). The CWV showed positive correlation, where watershed terrain consisted fine texture, but negative correlation with schist and gneiss.

5. Conclusion

Among all the watersheds, the watersheds no.10 and 8 were concluded as most susceptible to stream erosion followed by Watershed no.7, 9, 2, 1, 6, 11, 3, 5, and 4. It is observed that there is a need of water conservation measures in watershed no.7 to manage high runoff and high release of water in a short time in climax flow. It was found that most lower regions of Eastern nayar of thalisain area are susceptible to fall in the very high to high erosion potential zone. While the western nayar part is still in the phase of moderate susceptibility. The Dothatoli ridge in the eastern part of the Thalisan, which is dominated by dense forest, alpine pastures, alpine scrubs, scree slopes, is low erosion prone. Low bifurcation ratio consistent variation across watersheds leading to elongated shape of basin, coarser texture, high relief and low length of overflow has made these watersheds susceptible to erosion. The rock formation, structure, barren and agriculture lands also influence the susceptibility of watersheds. Therefore, the study suggests that soil and water conservation must be implemented in the all the 11watersheds to control the fluvial erosion. Planning must be generated with the help of geospatial technologies and field derived information to devise suitable soil and water conservation measures and appropriate site for the implementation.

Amit Kumar, Ravinder Dhiman and Benidhar Deshmuk (2014) carried a similar type of study in the Kangra region of Himanchal Pradesh of Indian Himalaya. There study gave emphases of geology of the area and how it was relating with the morphometric paraments and both affecting the watershed erodability.

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