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Soil Erosion Risk and Flood Behaviour Assessment of Sukhnag catchment, Kashmir Basin: Using GIS and Remote Sensing

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Abstract

Kashmir Basin is surrounded on all sides by lofty mountains, there is only one outlet i.e., Jhelum River to drain water from the basin. The mountainous areas of Kashmir Basin have rugged topography and unstable slopes with highly shuttered rocks. Based on these factors, the evaluation of basin characteristics from the morphometric analysis and other associated factors will help to understand the physical behaviour of the area with respect to floods and soil erosion risk. Remote sensing and GIS techniques were applied to extract drainage network using Digital Elevation Model (DEM) to evaluate morphometric parameters for Sukhnag catchment. Lineament, slope and aspect maps were generated to support morphometric parameters to demarcate the soil erosion and flood prone areas during harsh weather conditions. In low lying areas with more habitation and construction on the river banks and flood plains have squeezed the rivers and minimized their water carrying capacity. Morphometry together with lineament density, slope distribution and flood plain conditions helps to classify the catchment into three categories, high, medium and low priority for conservation and management with respect to soil erosion and floods. Among 14 sub-watersheds SF1, 2, 5, 6 and 7 are more prone to landslides and SF10, 12, 13 and 14 are more prone to flood and siltation hazard. More chances of erosion risk in SF1, 2, 5, 6 and 7 can be due to lose upper layer, high altitude, unstable slope and high structural density. Conversely, the floods and siltation hazard are more in low lying sub-watersheds as faced in Kashmir Valley (Sept. 2014 Flood). The present work emphasized that categorization of smaller hydrological unit's i.e., sub-watersheds are ideally recommended for initiating soil conservation and flood mitigation measures in the area.

Keywords: Soil erosion; Flooding; Morphometric analysis; Kashmir basin; Himalaya

Introduction

The study of the physical behaviour of the catchment helps in understanding the hydrologic and geomorphic problems like flooding, erosion and mass movement [1]. Morphometric analysis of a watershed provides a quantitative description of the drainage system, which is an important aspect of the characterization of watersheds [2]. This analysis can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution [3]. The morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behaviour of a watershed if correctly coupled with geomorphology and geology [4]. The hydrological response of a river basin can be interrelated with the physiographic characteristics of the drainage basin, such as size, shape, slope, drainage density and length of the streams etc. [5,6].

The quantitative analysis of morphometric parameters is of immense utility in river basin evaluation, watershed prioritization for soil conservation and water resources management (flood risk and sustainable floodplain management) at micro level. The morphometric study involves the evaluation of stream parameters through the measurements of various stream properties [7-10]. Morphometry also described as the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [11,12]. The development of landforms and drainage network depends on the bed rock lithology and associated geological structures, hence, information on geomorphology, hydrology, geology and land cover can be obtained by the reliable information from the study of drainage pattern and texture [13]. The role of lithology and geological structures in the development of stream networks can be better understood by studying nature and type of drainage pattern and by a quantitative morphometric analysis [3].

However, not only morphometry, the importance of structural analysis related to landslide assessment cannot be ignored. The utility of lineament mapping is one way of incorporating structural information into the landslide hazard assessment [14-18]. Lineament is an extended mappable linear or curvilinear feature of a surface whose parts align in straight or nearly straight relationships that may be the expression of folds, fractures, or faults in the subsurface [19]. However, taking landslides as a major concern, lineaments (faults and fractures) are more important because they act as weak lines or zones and enhance the potentiality of that particular area with respect to landslides.

Since the time immemorial, floods are one of the most recurring and frequent natural calamity faced by mankind. Occurrence of flooding in any area causes serious vulnerability to economy, population and environment. The areas more prone to flood hazard are also be assessed by the application of drainage morphometry [20-24]. The tributaries of the river basin contribute more water in the main river causing floods in low lying areas; with each sub-catchment has its

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own distinct influence on the main river due to varying drainage morphometrics [25]. In Kashmir Basin, the intense rainfall in September 2014 and March 2015 with support of water-logging problems and low water transport capacity of river channels caused flooding in low lying areas. The unforgotten flood in September 2014 caused massive damage to the life and property particularly in flood plains of Jhelum River. In the plainer areas, other causative factors which contribute a lot in bringing floods are land use pattern in which uncontrolled construction along river banks and flood plains are serious issue.

Influence of drainage parameters and other causative factors in bringing landsides and floods can be assessed to isolate the areas prone to land sliding (soil erosion) and flooding. The watershed behaviour supported by parameters like lineaments, lithology, slope and past experiences of natural disasters will help in preparation of conservation and management strategies.

Geological Setup of Area

The Sukhnag catchment is one of the sub-catchment draining an area of about 1008 square Kilometers. The present study area is in Kashmir valley, northern India, NW Himalaya (Figure 1), between latitude 33°54′ to 34°15′ N and longitude 74°15′30″ to 74°48′ E. The Kashmir basin has geological record ranging from Precambrian to Recent (Figure 2). The rocks present in the present area are Panjal traps, limestone, Agglomeratic slates, Shales, Karewas and alluvium. Panjal traps, limestone and agglomeratic slate are lying in the extreme west, karewas (Plio-Pleistocene) are fluvioglacial sediments covering most of the area in middle and the recent alluvium covering flood plain near Jhelum River.

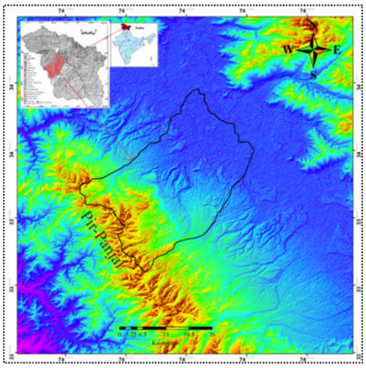

Figure 1: Location map of Sukhnag - Ferozpur watershed of Kashmir Valley, India.

Geomorphologically, the area consists of mountain tops, plains, canyons (deeply incised streams) and open slopes. The Pir-Panjal side of the area has a very complex and rugged topography with very high relief and steep slopes which have provided a better understanding of the geomorphic processes prevailing in the area. The presence of high relief controls steepness which in turn controls the energy available for driving forces such as runoff in the area. Thus, based on the geomorphological characteristics, the area is divisible into three zones. The first zone beginning from its southwestern side are identified as rocky uplands which is characterized by high, steep rocky mountains with deep and narrow fluvial valleys. The zone remains snow covered most of the year. The middle zone includes tilted lower and upper karewas corresponding to a wide and gently sloping pediment which directly overlies the basement rocks of Panjal Traps/Triassic limestone etc. The third zone is flood plain zone which is characterized by wide alluvial deposits brought by streams from uplands.

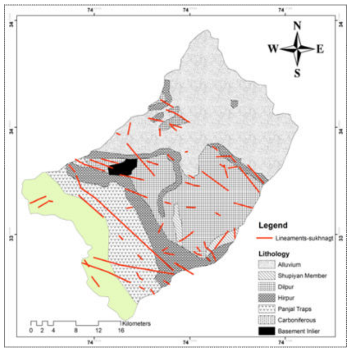

Figure 2: Geology of the study area as derived from PCA and existing geological map.

Data Base and Methodology

For the assessment of watershed behaviour with respect to landslides and floods following data base and methodology are used. The Geographical Information System (GIS) has been used for preparation of various thematic layers using various data sources and data preparation methods for assessment of soil erosion risk [26]. Morphometric analysis was carried out to relate effects of different parameters on landslides and floods in the area. The morphometric conditions are highlighted by using satellite imagery, ASTER DEM (30 m resolution) and Survey of India (SOI) topographical maps (1: 50000 scale). The software's utilized are Arc GIS 10.2, Global Mapper and ERDAS Imagine 9.1 in geo-registration of toposheets as well as for geo-rectification, image processing, digital image classification and composition of false colour composite (FCC) from satellite data. The digitization, computation of spatial as well as attribute database for the drainage system analysis is done in Arc GIS 10.2. The digital elevation model (DEM) products like drainage network map, elevation map, slope map, and contour map were integrated by overlay technique in Arc GIS to assess their effect on the watershed behaviour (Figure 3).

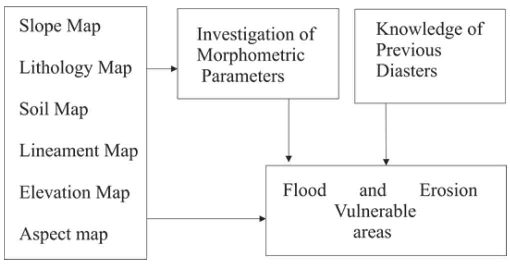

Figure 3: Flow Chart of Methodology

Watershed with drainage network was delineated with the help of ARC GIS 10.2 software (Figure 4). Inlet and outlet are defined to demarcate Sukhnag–Ferozpur catchment. Sub-watersheds are also delineated based on water divide line obtained from watershed raster layer derived from DEM in hydrology toolbox of ARC GIS, and morphology of terrain observed on the topographic maps and then sub-basin wise morphometric analysis was carried out using the same software. Drainage pattern is characterized by irregular branching of tributaries in many directions with an angle less than 900. The catchment is divided into 14 sub-watersheds with codes SF1 to SF14. The results obtained from each parameter are separately given below:

Stream ordering is the most important parameter for drainage basin analysis. The total number of streams found is 1766 out of which 1369 are of first order, 297 of second, 75 of third order, 19 of fourth, 5 of fifth and 1 of sixth order. The variation in order and size of the sub-watersheds is largely due to physiographic and structural conditions of the region. The total length of stream segment is high in first order streams and decreases with increasing order [27]. This variation observed indicates that the flow of streams is from high altitude with lithological variations and moderately steep slopes [28]. Stream length ratio between successive stream orders varies due to differences in slope and topographic conditions and bears a significant relationship with the surface flow discharge and errosional stage of the basin.

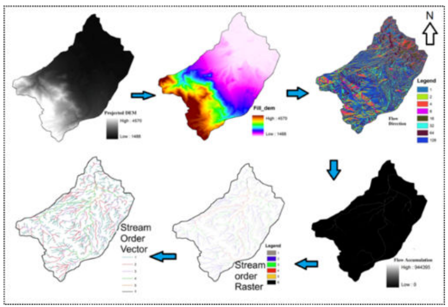

Figure 4: Extraction of drainage map of watershed with stream order in Arc GIS environment.

Linear parameters

Drainage density (Dd) indicates closeness of spacing of streams in a region [29]. Drainage density varies with climate and vegetation [25], soil and rock properties [30], relief and landscape evolution processes. In this study, high drainage density was found in SF1, 2, 5, 6, 7, 8 and 11 because of impermeable subsurface material and mountainous relief. Drainage density map (Figure 5) of catchment clearly indicates high slope and impermeable rock types present in these sub-watersheds. High Dd reveals a highly dissected watershed with a relatively fast hydrological response to rainfall events, while as low Dd means a watershed is poorly drained with a slow hydrologic response [2]. It has been observed that low drainage density is found in highly permeable and low relief areas while as high Dd for the regions of impermeable surface and mountainous relief [31].

The Stream frequency is defined as the total number of stream segments of all orders per unit area [29]. The direct relationship of drainage density and stream frequency with runoff processes was analyzed [32]. The sub-watershed SF1, 2, 6, 7 and 8 have high stream frequency because they fall in the zone of fluvial channels and the presence of ridges on both sides of the valley. The sub-watershed with low relief like SF10, 12, 13 and 14 are having low stream frequency. Generally high stream frequency is related to impermeable sub surface material, sparse vegetation, high relief and low infiltration capacity of the region. Sub-watersheds having highest value of stream frequency produce faster runoff, resultant faster runoff makes the sub-watersheds susceptible to floods lying in downstream.

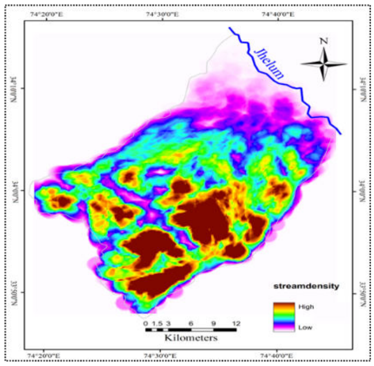

Figure 5: Drainage density map of area.

The low drainage density of sub-watershed SF13, 14, 10, and 12 may be because of indiscriminate anthropogenic influence on the land use pattern as observed in the area. The high drainage density sub-watersheds provoke a quick flood response which results in higher runoff in downstream in these low density area with resultant flood vulnerability. From the data following interpretations can be made, first one in mountainous sub-watersheds chances of erosion are more because of quicker runoff process and second is that in lower plainer sub-watersheds low stream frequency, low drainage density, slower runoff and higher over land flow enhances chances of flooding and deposition of mud brought with flood water from mountainous terrain as monitored in September 2014 Jammu and Kashmir devastating flood. The drainage frequency and drainage density have been collectively defined as drainage texture. The Drainage texture is defined as the total number of stream segments (Nu) of all orders per perimeter (P) of the area [29]. In geomorphology, drainage texture is an important concept related to relative spacing of drainage lines [33,34]. High drainage density gives rise to fine texture while low drainage density gives rise to coarse drainage texture [25]. The drainage texture depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development [35] and classified drainage into five classes i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). The drainage texture in the area was found to vary from 0.58 to 6.86. The fine drainage texture sub-watersheds hints towards impervious subsurface [34] results high runoff, which makes coarse textured (SF10, 12, 13, 14) more prone to floods during intense rainfall.

Bifurcation ratio is related to the branching pattern of a drainage network and is defined as the ratio between the total numbers of stream segments of one order to that of the next higher order in a drainage basin [36]. The value of mean bifurcation ratio fluctuates from 2.21 to 3.20 indicating structural control in drainage development in southwestern sub-watersheds and shows a clear relationship with the lineaments and lithology. The high bifurcation ratio indication strong structural control on drainage pattern while as others show comparatively less structural disturbances (Figure 6). Structures found in lithology (also covered by upper loose soil layer) bring the area in the category prone to landslides. The analysis of mean bifurcation ratio reveals presence of high flow energy result of which

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does not offer ample time for infiltration, leads flood hazard during heavy rainfall storm. This suggests that in addition to earthquakes, landsliding may be caused by presence of structures in high altitudinal terrain. During intense and continuous raining, loosening and seepage of water through these structures acts as lubricant and intern causes landsling as observed in devastating flood (Sept. 2014 and March 2015) occurred in Jammu and Kashmir after decades of years. Length of overland flow (Lo) is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of drainage density [29]. It is most important independent variables affecting hydrological and physiographical development of a drainage basin. The shorter length of overland flow for SF1 pointed out the quicker runoff process whereas higher length of overland flow for SF14 pointed out slower runoff process.

The sub-watersheds having lower 'Lo' and quicker runoff brings water quickly from upstream into low lying sub-watersheds. Consequently, sub-watershed 10, 13 and 14 having higher length of over land flow becomes more susceptible to floods during intense rainfall. Besides, higher length of over land flow and slower runoff gives more time for settling of mud coming with flood water during flooding as seen in recent flooding (September 2014) in Jammu and Kashmir. So, siltation is another serious environmental problem other than land sliding and direct damage caused by flood water to everything coming in its way. In this regard, it will be crucial of removing possible hazard of flooding in the habitant areas which are situated in plainer low lying, flood plains, or low stream density areas of Kashmir Valley situated in the (Himalayas) prone to landslides.

Shape parameters of sub-watersheds of drainage basin

Form factor is defined as the ratio of basin area (A) to the square of the basin length (Lb) [37] and characterize the shape of the basin. The values of form factor would always be less than 0.7854 (perfectly for a circular basin). Form factor value for all sub-watersheds ranges from 0.12 to 0.78. High value of form factor states the circular shape of basin and smaller the value of form factor more elongated will be the basin. The observation shows that the SF12 and SF9 watersheds are highly elongated and will have a flatter peak flow over longer duration. These Peak flows elongated sub-watersheds are easier to manage than from the circular sub-watersheds. The elongation ratio is defined as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin [36]. Analysis of elongation ratio indicates that the areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in the discharge of runoff than an elongated basin [28]. The values of elongation ratio generally vary from 0.6 to 1.0 over a wide variety of climatic and geological conditions. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope [2]. Value of the elongation ratio found in the area ranges from 0.39 to 0.99 indicating high relief and moderate to steep slope. Circulatory ratio is helpful for assessment of flood hazard which mainly concerned with the length and frequency of streams, geological structures, landuse/landcover, climate, relief and slope of the basin [33]. Circulatory ratio is found in the range of 0.31 to 0.74 which is less than unity and indicates that the sub-watersheds are almost elongated. The circulatory ratio is very much useful parameter in assessment of flood vulnerability of area. If circulatory ratio is higher, higher will be flood risk at a peak time at the outlet point. The outlet point of higher circulatory sub-watershed becomes one of the inlet points for lower circulatory ratio sub-watershed coming on downstream side. This analysis reveals that the extreme downstream subwatersheds (i.e., SF 9, 12, 13 and 14) having low circulatory ratio are more prone to floods.

Relief aspects of drainage basin

The relief aspects of sub-watershed are also important in water resources studies, direction of stream flow analysis and denudation conditions of the watershed. Relief aspects like basin relief (H), relative relief (Rp), relief ratio (Rh) and ground slope or ruggedness number (Rn) were measured. Basin relief is an important factor in understanding the geomorphic processes and landform characteristics. Schumn [36] has measured it along the longest dimension of the basin parallel to the principle drainage line. It varies from 300 to 1995 meters. The watersheds have been divided into high, medium and low relief regions in which sub-water SF7, 11, 6, 8, 2, 1, 3 and SF4 are having highest basin relief (Figure 6a). The high relief indicates low gravity of water flow as well as infiltration and high runoff conditions as well as sediment down the slope. Relief ratio is the ratio of basin relief to the horizontal distance on which relief was measured [36]. It measures overall steepness of the watershed and is also considered as an indicator for the intensity of erosion process occurring in the watershed. The relief ratio for watersheds varies from 0.014 to 0.241. High value of relief ratio is the characteristics of the hilly region. The higher values of relief ratio SF 6, 7, 8, 1 and 2 indicate steep slope and high relief (Figure 6), while the lower values for SF 9, 10, 12, 13, and 14 indicated presence of lower degree of slope [38]. The high relief ratio with steep slope has more landside chances while as area with low relief ratio has higher degree of flood vulnerability during intense rainfall.

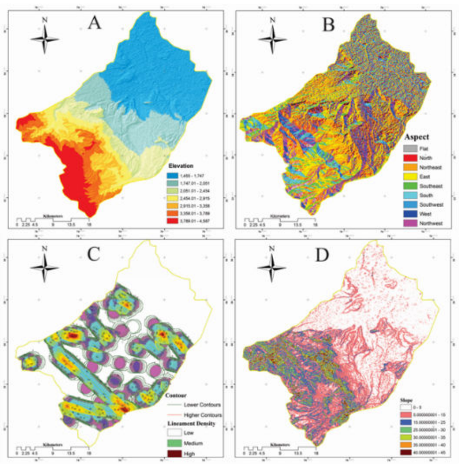

Figure 6: a) Elevation; b) Aspect; c) Lineament density; d) Slope characteristics of the watershed.

Relative relief (Rr) is the ratio of relief (H) to the perimeter of basin. It is an important morphometric variable used for the overall estimation of morphological characteristics of terrain. The relative relief for watersheds varies from 0.00006 to 0.083. The watersheds having higher relative relief have higher runoff potential than others. Ruggedness number (Rn) is the ratio of relief and horizontal distance. It is the product of drainage density (Dd) and relief of the basin in the same unit [27, 32]. For sub-watersheds the ruggedness value obtained ranges from 6.615 to 0.252. According to Strahler [27], the ruggedness index of topography point towards the extent of instability of land

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surface. The low ruggedness value of SF10, 12, 13 and 14 indicate less prone to erosion and highly prone to floods. The ruggedness value is higher in SF6, 7, 8, 11, 2 and 1 with higher basin relief and drainage density values. As the slope is very steep linked with its slope length and aspect helps to initiate landslides during intense rainfall in these sub-watersheds (Figures 6b and 6d). The location of watershed is in Himalaya, construction of new roads in rugged terrain can enhance and contribute to slope failure process. Road cuts seen in ridges are always having steeper slope than natural slope of that particular ridge, and roads can modify the flow of surface water draining downslope. The steep slope with associated road is one of the cause in bring landslides. The landslides in the area are also resulted by constructing building and other structures without taking grading of slopes into consideration. The profiles generated across the valleys present in the hilly area are mostly found to be V-shaped and U-shaped (Figure 7) also supports the steepness of slopes.

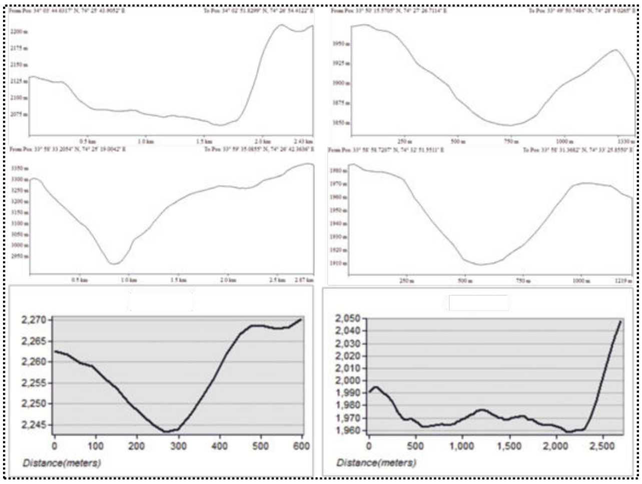

Figure 7: Shows V-shaped and U-shaped valleys present in the hilly areas.

The parameters like lithology, slope, aspect, elevation, lineaments/ structures, and drainage characteristic etc can be grouped as basic variable in determining the landslide vulnerability/ susceptibility, but other causative factor/variable which cannot be negotiated as intensive rainfall and earthquakes in the area. Here in this study, the rainfall has been considered because it triggers landslides in elevated, steep slopes, and highly structured areas (Figure 8). In the area, where structural weak planes like joints, faults, bedding planes, and foliation are present in rocks, becomes the area of moisture accumulation.

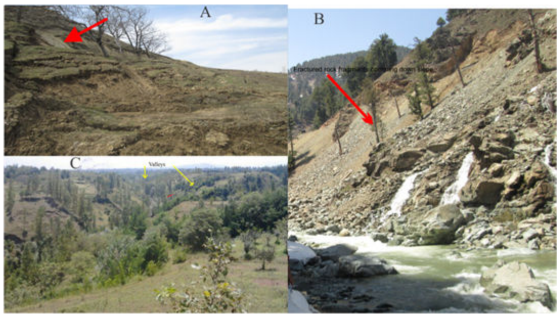

Figure 8: a) Huge landslide after intense rainfall, b) Ridge in which slope associated with highly fractured rock fragments come down-slope, c) presence of valleys in the area.

The surface material structures and permeability of terrain is severely influenced by structures/lineaments and as a result slope stability is affected [39,40]. The increase in permeability by structures enhances moisture content, which intern accelerates the rate of weathering, worsens the instability problems of land in the area. In groundwater studies, lineament density has been utilized because of fracture and permeability relationship [41-43], will enhance the chances of occurrence of landslides. The Karewas deposits are weak as compared to other rock types, resultant erosion/landslide can be observed by the presence of valleys (small and large sized) in the area (Figure 8c).

Results and Discussion

The morphometric parameters and other factors were taken into consideration to assess the landslide and flood influencing characteristics in each sub-watershed. The linear parameters such as drainage density, stream frequency, mean bifurcation ratio, drainage texture, and length of overland flow have a direct relationship with erodibility while as shape parameters such as elongation ratio, circularity ratio, form factor, basin shape and compactness coefficient have an inverse relationship with erodibility [44]. The highest value of the linear parameter was ranked 1, the second highest value ranked 2, and so on. In the Sukhnag-Ferozpur catchment, SF1, 2, 5, 6 and 7 are given high rank and 3, 4, 8, 9 and 11 medium rank and 10, 12, 13 and 14 are assigned low rank in terms of soil/land erodibility. However, taking landscape (plainer area), their low water carrying capacity i.e., low stream frequency, low drainage density and settlements of flood plains makes SF10, 12, 13 and 14 sub-watersheds more prone to flood hazard. Thus, in the area some subwatersheds are prone to landslides while as some are flood prone at the time of intense rainfall (Figure 9).

The areas (sub-watersheds) more prone to landslides are coming towards the mountainous region where the geological structures (joints, bedding planes etc) are more, and upper soil cover is weak. According to Ali and Ali [45], in the Kashmir basin, the high altitude areas have more concentration of lineaments engulfed by steep slopes covered by loose soil cover. Choubey and Ramola [46] highlighted various factors like geology, adverse natural topography like steep slopes, weathered rocks and soils, human influences on the topography, and high rainfall in bringing the landslides. Additionally, the hills have steep slopes are vulnerable to landslides [47] with elevation ranging from 1488 m–5000 m amsl. Other important causative factors of producing landslides in hilly regions are the

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intensity and duration of rainfall. Because during intense and continuous raining, loosening and seepage of water through these structures acts as lubricant and intern causes landsling as observed in devastating flood (Sept. 2014 and March 2015) of Jammu and Kashmir after decades of years. So drainage characteristics and the past landslide location in the area is the first step towards the reduction of landslide hazard (Table 1).

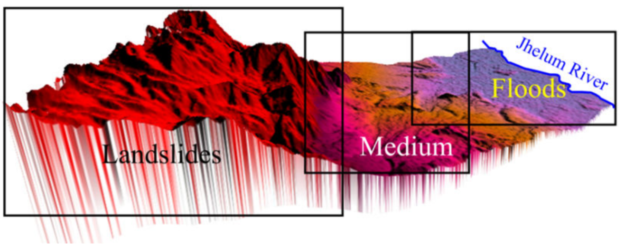

Figure 9: Final Priority classes of Sukhnag Catchment in which hilly terrain is at higher risk of soil erosion and low lying area to floods during heavy rainfall.

Micro Watershed	(Dd)	(Fs)	(Rb)	(T)	(Rf)	(Bs)	(Rc)	(Cc)	(Re)	CP
SF1	1	1	1	1	10	3	9	6	11	4.78
SF2	7	5	3	2	12	1	13	1	13	6.33
SF3	10	6	6	4	8	5	9	5	9	6.88
SF4	9	7	1	3	8	6	8	7	8	6.33
SF5	4	8	2	5	11	2	10	4	12	6.44
SF6	2	2	9	6	9	4	11	3	10	6.22
SF7	5	3	5	8	4	11	4	11	4	6.11
SF8	3	4	7	9	6	8	6	9	6	6.44
SF9	8	10	8	10	2	13	2	13	2	7.55
SF10	12	12	10	11	7	7	12	2	7	8.88
SF11	6	9	4	7	5	9	7	8	5	6.66
SF12	11	11	7	12	1	14	1	14	1	8.00
SF13	13	13	11	13	4	10	5	10	4	9.22
SF14	14	14	12	14	3	12	3	12	3	9.44

Table 1: Prioritization results of Morphometric analysis and compound parameter.

The parameters like drainage density, water carrying capacity of river during intense rain fall, settlements on banks and flood plains, when taken into consideration leads us to know the areas more affected by floods and flood generated hazards. Sub-watersheds having highest value of stream frequency produce faster runoff, resultant faster runoff makes the sub-watersheds susceptible to floods lying downstream. The low drainage density of sub-watershed SF13, 14, 10, and 12 may be because of indiscriminate anthropogenic influence on the land use pattern as observed in the area. The high drainage density sub-watersheds provoke a quick flood response which results in higher runoff in downstream in low density area with resultant flood vulnerability. In geomorphology, drainage texture is an important concept related to relative spacing of drainage lines [33, 34]. High drainage density gives rise to fine texture while low drainage density gives rise to coarse drainage texture [25]. The fine drainage texture sub-watersheds gives evidence towards impervious subsurface [34] which results high runoff, leads coarse texture sub-watersheds SF10, 12, 13, and 14 more prone to floods during intense rainfall. The lower length of over land flow and quicker runoff of upstream sub-watershed brings water quickly into sub-watershed 10, 13 and 14 makes them more susceptible to floods during heavy rainfall. Higher length of over land flow and slower runoff gives more time for mud coming with flood water to settle as seen in recent flooding (September 2014) in Jammu and Kashmir. So siltation is another serious environmental problem other than direct damage caused by flood water to everything coming in its way (Figure 10). In this regard, it will be crucial of removing possible hazard of flooding in the habitant areas which are situated in plainer low lying flood plains.

Figure 10: Siltation problems faced during 2014 flood in Kashmir Valley in lower plainer areas.

In flood vulnerability assessment, circulatory ratio is found very much applicable parameter. Higher the circulatory ratio higher will be flood risk at a peak time at the outlet point. The outlet point of higher circulatory sub-watershed becomes one of the inlet points for lower circulatory ratio sub-watershed in downstream. Thus extreme downstream sub-watersheds 9, 12, 13 and 14 having low circulatory ratio are more prone to floods. High value of relief ratio is the characteristics of the hilly region. The high values of relief ratio for SF 6, 7, 8, 1 and 2 indicated steep slope and high relief, while the lower values for sub-watershed 9, 10, 12, 13, and 14 indicate presence of lower degree of slope [38]. The sub-watersheds having low relief ratio point towards higher degree of vulnerability with respect to floods.

By watershed prioritization, one can come to know which watershed can lead higher amount of discharge due to an excessive amount of rainfall [24]. The water which comes from higher reaches and during heavy rain fall drains through Jehlum River. Jehlum River is not able to concentrate all the flood water, resultant over bank flow and river bank failure causes damage to life and property. The uncontrolled settlements on river banks and flood plains and their consequence in causing floods in any area cannot be neglected. The outcome of this study will assist the local inhabitants, engineers and urban planners to minimize loss of life, property and nature by means of prevention, mitigation, and avoidance caused by landslides and flooding. The main causes of the past landslides and floods will be useful for making quick decisions and future plans for mitigation and reduction of hazards due to landslides and floods in the area.

Conclusion

The Drainage basin characteristics through remote sensing and GIS demonstrate its utility in categorizing the watershed situated in highly rugged terrain of Himalayas. Drainage analysis with the support of lineaments and lithology illustrated their connection with landsliding and flooding behaviour of the watershed. Results of categorization elucidates that sub-watersheds SF1, 2, 5, 6 and 7 fall under high priority in terms of susceptibility to soil erosion because of lose upper layer, high elevation, high lineament density, and unstable slopes. In contrast, the low lying sub-watersheds like SF10, 12, 13 and 14 falls in the category more prone to flooding which results in associated siltation hazards and other environmental problems. This study thus illustrates the applicability of spatial technology in predicting natural hazards possible due to landslides and also minimizing the flooding and siltation problems of the plainer sub-watersheds as observed in recent flooding (Sept. 2014 and March 2015) in Kashmir valley and surroundings. High erosion rate or landslide in the hilly area results from heavy rainfall, structural weak planes in hard rocks and loose upper soil cover which drives rapid physical erosion. In highly urbanized settings, rainwater cannot infiltrate asphalt and cement and there may be little or no vegetation to slow sheetwash. Plainer areas with low drainage density, low frequency, slower runoff, and higher overland flow can face more floods and flood related problems. Thus, the systematic analysis of morphometric parameters and other factors derived from SRTM DEM using GIS environment are useful to highlight the watershed characteristics with respect to soil erosion and floods faced in intense weather conditions.

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