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Application of Geospatial Techniques in Soil Erosion Assessment in Sarbari Khad Watershed of Himachal Pradesh, India

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Abstract

The accurate measurement of geomorphometric parameters is crucial for assessing the condition of watersheds, particularly in mountain ecosystems and extensive areas where it can be challenging to obtain precise measurements. In this study, drainage density was used to evaluate soil erosion in the Sarbari Khad watershed located in the lesser Himalayan region of Himachal Pradesh, India, using Geographical Information System (GIS) and remotely sensed digital data. The analysis of drainage density indicated that the Sarbari Khad watershed is susceptible to surface erosion and soil degradation. The watershed was classified into low, moderate, severe, and very severe erosion categories based on the drainage density values, which revealed that about 50 percent of the area suffers from very severe erosion. The findings of this study suggest that drainage density can be used as an effective indicator for estimating erosion status of watersheds. This information can be used to prioritize watershed areas for soil and water conservation measures, which are critical for ensuring the sustainability of the watershed. Overall, this research work highlights the significance of using GIS and remotely sensed data along with direct survey-based topographical maps for assessing soil erosion in mountain ecosystems and extensive areas. The results of this study can be used to guide conservation efforts and inform policy decisions aimed at mitigating the negative impacts of soil erosion on the environment and local communities.

Keywords: *Soil erosion, Drainage density, GIS, Integrated watershed management, Remote Sensing, Climate Change.*

1. Introduction

India is a rich country in terms of the total water resource potential. India has 4 percent of world water resource (Saroha, 2017). The spatial and temporal concentration of monsoon is strongly associated with high rates of soil erosion. The highland areas like the Himalayan watersheds are highly prone to soil erosion and land degradation, especially during the monsoon season. Soil erosion in India is widespread and a serious threat to survival and well-being. The most important agent of soil erosion in India is running water. Though the process of soil erosion is natural and occurring since time immemorial but it has become a serious problem due to increased anthropogenic interferences over the period of time (Saroha, 2017). Singh et al., (1990) estimated that the average annual soil loss is about 15.2 tonnes per hectare and at national level it amounts to about 5 billion tonnes annually. Sehgal &Abrol (1994) have estimated that water and wind erosion in India extends over about 162.4 million-hectare area and out of this about 91 percent is water eroded area. Thus, approximately 50 percent of the geographical area of India is prone to various degrees of soil erosion and other forms of land degradation. This problem is most intense in the Himalayan watersheds. This has impacted not only in terms of decline in per capita availability of land but also in terms of qualitative loss and reduced productivity of soils in these watersheds where primary activities are the main source of livelihood. Therefore, the need of the hour to assess the degrees of soil erosion in different parts of these watersheds (Kumar et.al. 2022). Integrated watershed management approach is required to control and prevent soil erosion as soil conservation and management is pre requisite to achieve the goal of sustainable development.

Drainage density is a quantitative measure used to understand the physical parameters of the morphology of a watershed or catchment.Horton (1945) defined drainage density as the stream length per unit area in the drainage basin or watershed. It is calculated by dividing the total length of channels by the total area of that hydrological unit or watershed. Thus, it represents average length of channels per unit area of the watershed. It is an efficient element for drainage analysis and it provides a better quantitative expression to the dissection and analysis of morphology the physical landscape. It is a fundamental characteristic of physical landscape with interface with other elements of the watershed such as – structure or local geology, climate, topography, edaphic factors (soil type and permeability) and extent of vegetative cover.

Drainage density has been used by scholars to assess and predict soil erosion potential and to predict flooding behavior in the hydrological units like watersheds and catchments. These predictions vary depending upon the diverse geological, topographic and climatic conditions prevailing in various watersheds. It has been observed (Nag, 1998) that, generally, areas with low relative relief, highly resistant or permeable structure and dense vegetative cover have low drainage density. On the other hand, the high drainage density has been found associated with high absolute and high relative relief, weak or impermeable structures and limited vegetative cover (Nag, 1998). High drainage density prevails during the youth stage of landscape development. According to Tucker et al., (2001) drainage density reflects the intensity to which a given landscape is dissected. Berger &Entekhabi (2001) concluded that high drainage density is strong association with highly dissected terrain and torrential runoff resulting into intense floods and intense soil erosion.

Therefore, it is noteworthy that drainage density is a good indicator and measure of physical and hydrological characteristics of a watershed. The torrential, with occasional cloud bursts, nature of rainfall along with seasonal concentration (about 75 percent of the annual precipitation during monsoon months) makes the Himalayan watersheds highly vulnerable and prone to soil erosion, landslides and flash floods. Anthropogenic interventions in the form of infrastructure expansion, land use/land cover changes and increasing population pressure further intensify these problems in the fragile watershed ecosystems of the Himalayas. The main objective of the present research work to assess soil erosion on the basis of drainage density analysis of the Sarbari Khad watershed of Himachal Himalaya.

Study Area

The Sarbari Khad Watershed is located in the Beas River Basin and covers an area of 930.30 Km^2. It is situated between 31°54' 30” N latitudes to 32° 6' 30” N latitudes and 76° 56' E to 77° 7' 40” E longitudes (Fig.1). The area is bounded by Pir-Panjal Range and Beas River and comprises of 13 villages in the Kullu and Nagar revenue blocks, including some parts of Kullu town. The population of the watershed is 15247 people, and agriculture (Gardner et al., 2002) is the main economic activity. Tourism is also an important economic activity in the study area (Gardner, 2002; Gardner et al., 2002; Kumar et al., 2022a & Kumar et al., 2022b).

The watershed experiences a warm subtropical climate in the summer season and a cold temperate climate in the winter season. The monsoon season brings torrential rainfall, and the average annual rainfall is about 1000 m, occurring during the south west monsoon from June to September. Some precipitation takes place during the winter season due to the western disturbances. The average annual snowfall in the region amounts to about 345 mm confined to the upper reaches and during the winter season only. The monthly temperature ranges from a minimum of 8.7°C in January to a maximum of 28.3°C in June. The minimum and maximum relative humidity in May and August is 63.3% and 78.7%, respectively. Evaporation is minimum during the coldest months of December and January, with values of 36.1 mm and 38.7 mm, respectively, while maximum evaporation is observed in June (165.0 mm), which is considered the warmest month of the year.

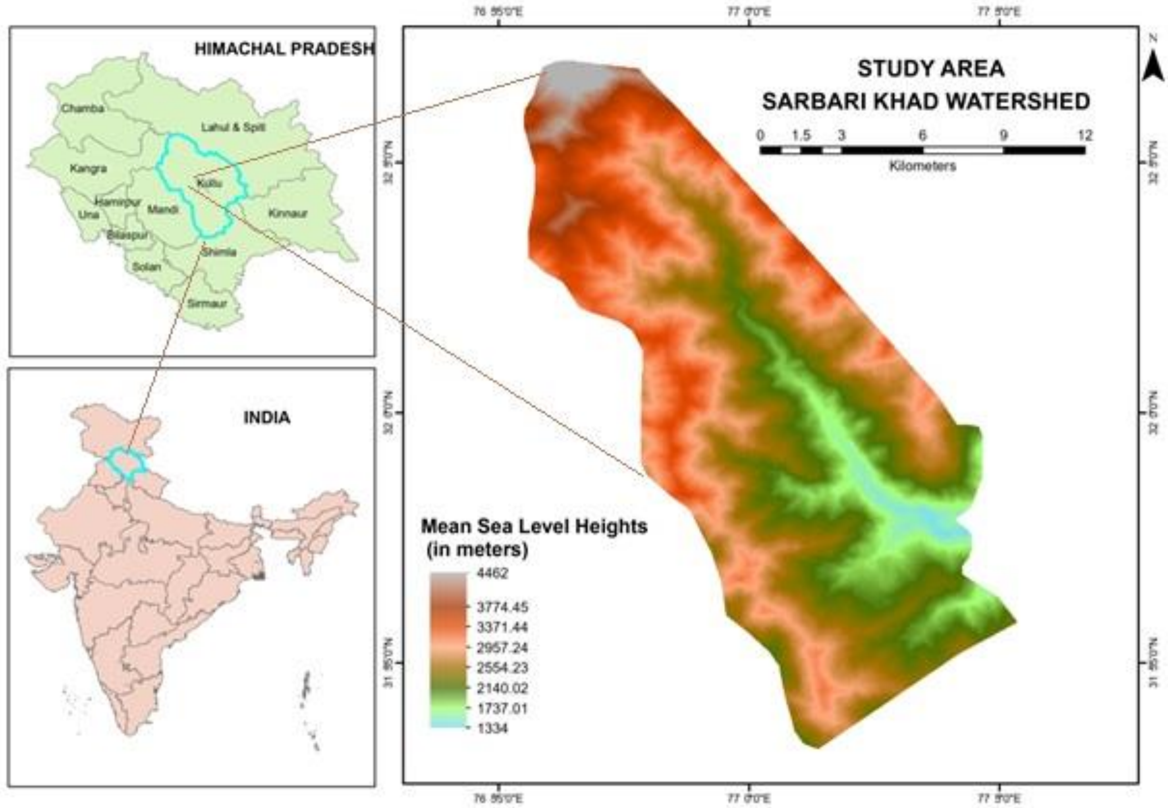

Figure (1) : Location map & Digital Elevation Model of the Study Area

2. Materials And Methods

This work is mainly based on assessing the drainage density and its implication on soil credibility. The boundary of watershed and drainage network was extracted through ASTER-DEM data and Survey of India topo- sheets. This data base has also been used to calculate slope and digital elevation of the area (Fig. 3 & 4). The remote sensing data were acquired from www.earthexplorere.usgs.gov. The development of stream networks relies on rainfall, slope and geology of that area. The watershed demarcation and the hydrological analysis of streams have been carried out in QGIS 3.16 software. Stream ordering has been successfully applied with a view to characterize watershed and drainage network. The parameters were sought from the streams extracted through ASTER-DEM data employing QGIS hydrological analysis tool. Drainage density, bifurcation ratio, drainage frequency etc. has been calculated through the already developed formulae (Fig.2).

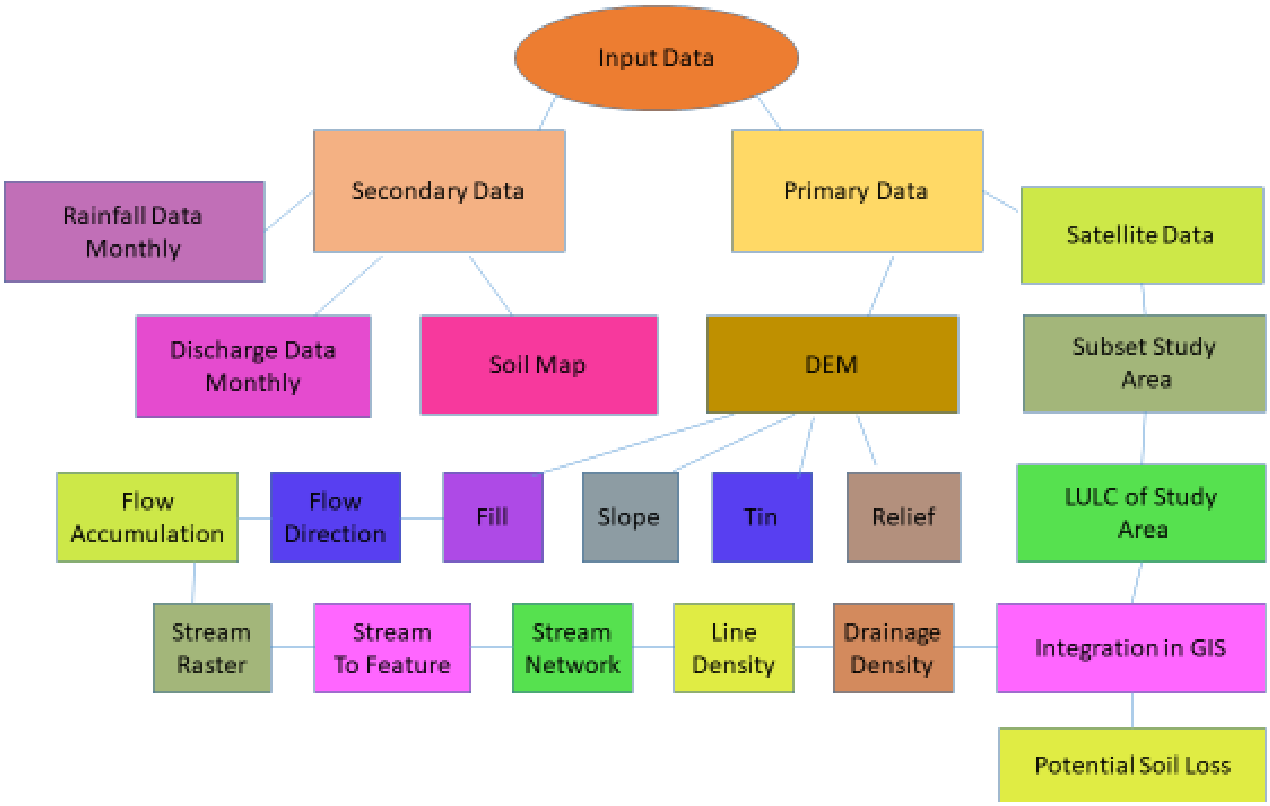

Figure (2) : Flow Chart of Hydrological process of SarbariKhad Watershed

Following method of Horton (1932) first of all the drainage density was calculated as the ratio of the total length of the stream channels of all orders to the total area of the watershed. The steps mentioned in the flow chart (Fig. 2) were followed for the calculation of drainage density (Fig. 1, 3, 4 & 5). Following the generalization of many research studies the soil erosion assessment was performed on the basis of drainage density differentials. Area under various degrees of erosion was evaluated as per the methodology suggested by Bucko and Mazurova (1958) and Mikhailov (1972). Rai et al., (2017), Kumari et al., (2021),applied a GIS-based approach in drainage morphometric analysis in Kanhar River Basin of India and concluded that drainage density is strongly correlated with valley density, channel head catchment area, topography, soil and structural characteristics, climate, vegetation and landscape development. Likewise, Pal &Saha (2017) have concluded that a strong positive correlation prevails between drainage density and the parameters such as: the number of stream merging points in the catchment, length of overland flow, the infiltration coefficient and drainage texture. Earlier Strahler (1964),Awasthi, et al., (2002), and Babu et.al., (2016), also concluded that areas of high drainage density have high runoff, coarse drainage texture and higher erosion potential. Singh (2010) applied the drainage density based methodology of Bucko and Mazurova (1958) and Mikhailov (1972) for assessing the soil erosion intensities in the Lesser Himalayan region watersheds.

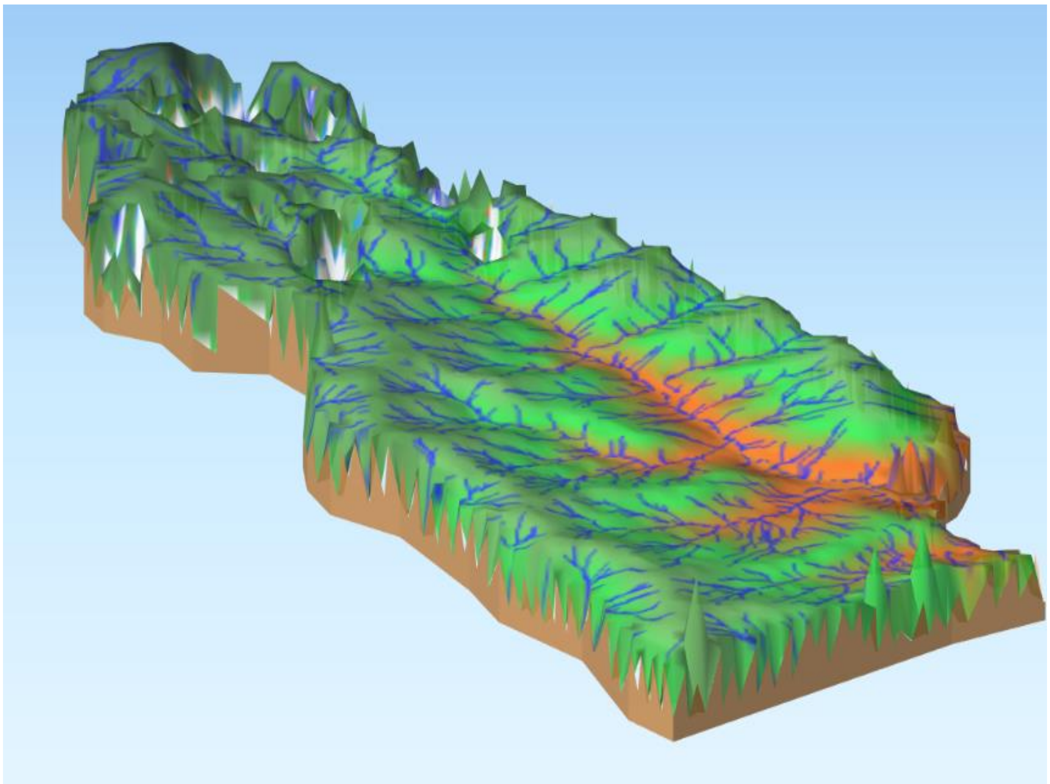

Figure (3) : 3D view of the Sarbari Khad Watershed

In view of all these studies, in the present study focus has been kept exclusively on relationship of drainage density with soil erosion. Although soil erosion is result of interplay of many complex factors such as rainfall erosivity factor, the soil erodibility factor, the length and degree of slope and land use/land cover characteristics, but keeping in view the limited variability of climatic, edaphic and vegetative factors in this small watershed, drainage density has been used as the main determinant of soil erosion. Drainage density parameter indirectly incorporates other factors also to a significant level in this scale of study. Therefore, in the present research work focus is exclusively on determination of soil erosion intensities based on drainage density variations in the Sarbari Khad watershed.

Table 1. Important Morphometric Parameter

Morphometric parameters	**Formula & definition**	**References**
Area of basin (A)	Plan area of the watershed (km^2)	Horton 1945
Bifurcation ratio (Rb)	Rb = Nu / Nu + 1 where Nu = number of stream segments present in the given order Nu + 1 = number of segments of the next higher order	Schumn 1956
Circularity ratio (Rc)	Rc = 4πA/P2 where A = area of basin,π = 3.14, P = perimeter of basin	Miller 1953
Compactness Coefficient (Cc)	Cc = 0,2821P/$A^{0,5}$ where P = basin perimeter, A = area of basin	Gravelius 1914
Constant channel maintenance (C)	Lof = 1/Dd where, Dd = drainage density	Horton 1945
Drainage density (Dd)	Dd = L/A where L = total length of stream, A = Area of basin	Horton 1945
Drainage Texture (Dt)	Dt = Nu / P	Horton (1945)
Elongation ratio (Re)	Re = √(A/π)/ Lb where A = area of basin, π = 3.14, Lb = basin length	Schumn 1956
Form factor (Ff)	Ff = A/(Lb)2 where A = area of basin, Lb = basin length	Horton 1945
Length of overland flow (Lg)	Lg = 1/2Dd where Dd = drainage density	Horton 1945
Length Area Relation (Lar)	Lar = 1.4 * A0.6	Hack (1957)

Mean stream length (Lsm)	Lsm = Lu/Nu where Lu = mean stream length of a given order (km), Nu = number of stream segments	Horton 1945
Perimeter of basin (P)	Perimeter of watershed (km)	Horton 1945
Shape Factor Ratio (Rs)	Sf = Lb2 / A	Horton (1932)
Stream frequency (Fs)	Fs = N/A where L = total number of streams, A = area of basin	Horton 1945
Stream length (LU)	Length of the stream	Horton 1945
Stream length ratio (RL)	RL = Lu / Lu-1 where Lu = total stream length of order (u), Lu-1 = the total stream length of its next lower order	Horton 1945
Stream number (Nu)	Nu = Total number of stream segments of order u	Strahler 1964
Stream order (U)	Hierarchical order	Strahler 1964
Texture ratio (T)	T = N1/P where N1 = total number of first-order stream, P = perimeter of basin	Horton 1945
Wandering Ratio (Rw)	Rw = Cl / Lb	Smart (1967)
Watershed Eccentricity (τ)	τ = [(|Lcm2 -Wcm2 |)]0.5/Wcm	Black (1972)
Channel Index (Ci)	Ci = Cl / Adm (H & TS)	Mueller (1968)
Valley Index (Vi)	Vi = Vl / Adm (TS)	Mueller (1968)

3. Results and Discussion

The total drainage or channels length of the watershed is 2137 km and out of this 1228 km is constituted by first order streams (Fig. 4 & 5). The average drainage density for the watershed as a whole is 0.5 km/ km². Within the watershed the drainage density varies from 1.07 to 3.30 km/km².The drainage density has been noticed in the category of high in the upper-central part of the Sarbari Khad watershed. This is strongly corrected with greater rainfall intensity in this part of the watershed.The maximum drainage density has been noticed in the southern part of the watershed and lowest drainage density was observed in northern part of the area which is mostly covered by snow.

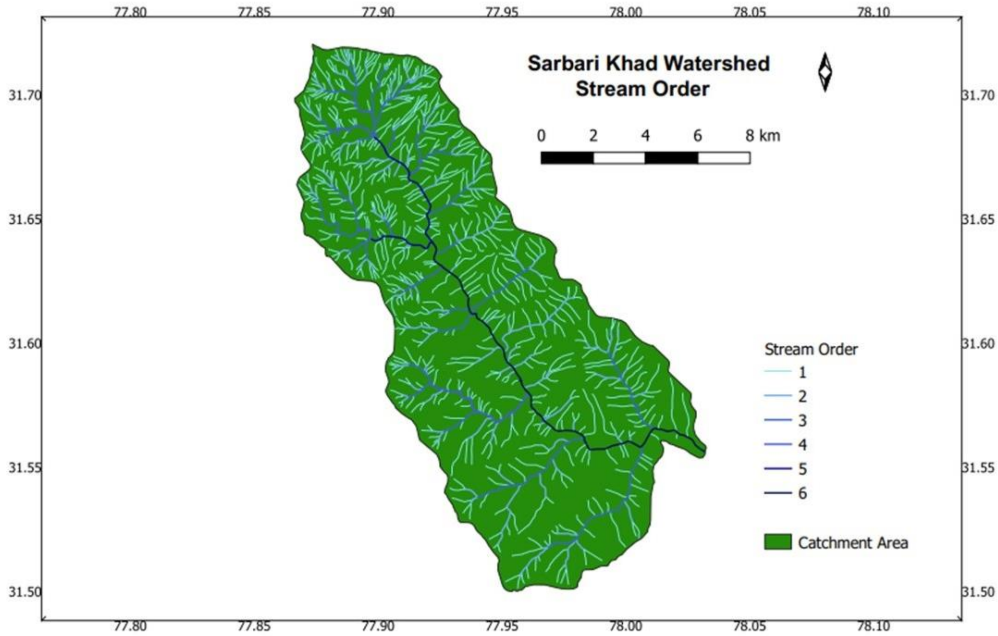

Figure (4) : Stream order of the drainage

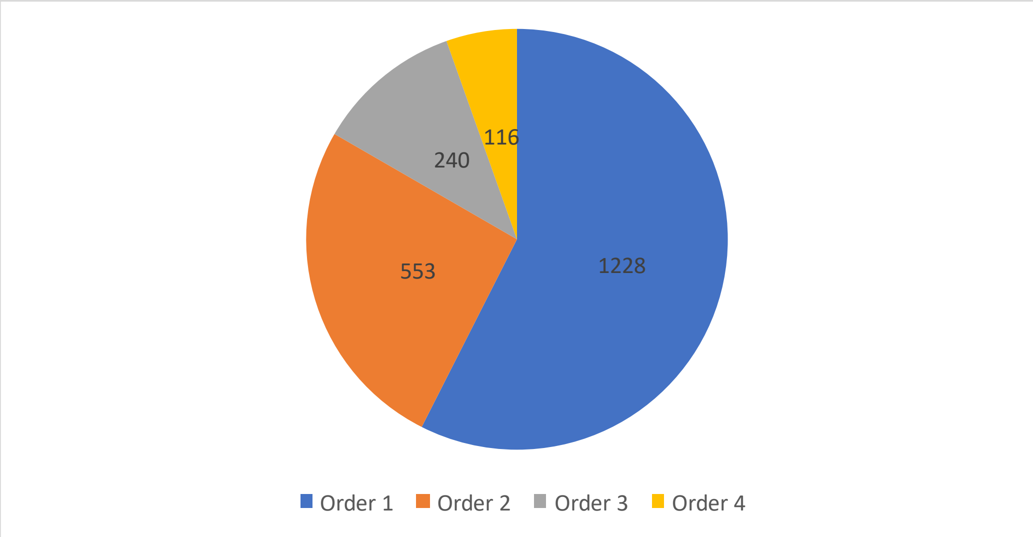

Figure (5) : Stream order wise stream length (length in kilometers)

The watershed has extremely resistant or permeable sub soil material with dense vegetative cover which may have advantaged low drainage density in north-eastern part of the region. The distribution of area under different classes of erosion has been given in table 1 for the study area. The drainage density indicates that majority area of the watershed comes in the category of severe to catastrophic rates of soil erosion.

Table 2. Distribution of area under different categories of erosion (Bucko &Mazurova, 1958)

Category	**Drainage Density(km/ km²)**	**Watershed Area(square km²)**	**Cumulative area(in %age)**	**Vertical assessment (Erosion degree)**
I	< 0.1	-	-	No erosion
II	0.1-0.5	-	-	Slight
III	0.5-1.0	-	-	Moderate
IV	1.0-2.0	408.4	45.1	Severe
V	2.0-3.0	453.8	50.4	Very severe
VI	> 3.0	48.2	5.2	Catastrophic

About 45.1 percent area of the total watershed area falls in the drainage density range of 1-2 km/km² and indicates severe level of soil erosion. The area with drainage density value of 2-3 km/km² indicates very severe erosion and constitutes about 50 percent of the total area of the watershed. About 5 percent area of the watershed falls in the highest drainage density category of above 3km/km² and is associated with catastrophic soil erosion potential. The severity of soil erosion in the Sabari Khad watershed is directly related to local geology, intense monsoon rains, high relative relief, land use/land cover changes, deforestation and expansion of infrastructure. This study indicates that the watershed is facing severe to catastrophic intensity of soil erosion. Splash erosion, sheet erosion, rill and gully erosion can be easily observed in different parts of the watershed during monsoon season. For the sustainable development of the watershed immediate application of different soil and water conservation techniques is required on priority basis. Afforestation, check on deforestation, overgrazing and faulty agriculture practices, contour farming, check dams, terrace farming, stabilizing of slopes and land use according to land capability classes should be operationalized at the earliest to avoid further intensification of problems.

Impact of climate change on soil erosion

The present trend of climate change has further increased the susceptibility of the soils in the Himachal Himalayan watersheds through adverse changes in temperature, precipitation and biotic factors. The impact of climate change on soil erosion rates is complex and multifaceted, involving numerous interacting factors that can either exacerbate or ameliorate the problem. One of the primary drivers of increased soil erosion rates is the expected increase in rainfall amounts Singh and Dev (2012) and intensities associated with global warming. As rainfall increases, so does the potential for soil erosion, with the ratio of erosion increase to annual rainfall increase estimated to be around 1.7. However, the impact of climate change on soil erosion is not just a function of rainfall amounts and intensities. Other factors such as shifts in land use, plant biomass production, plant residue decomposition rates, soil microbial activity, and evapo-transpiration rates can also play a significant role. For example, decreased biomass production resulting from changes in temperature, solar radiation, and atmospheric CO2 concentrations can make soil more susceptible to erosion, even in cases where annual rainfall would decrease. One of the key findings of recent studies is that farmers' response to climate change can potentially exacerbate or ameliorate the changes in erosion rates expected Karmakar et.al. (2023). For example, changes in land use practices such as tillage, crop rotation, and cover cropping can have a significant impact on soil erosion rates Maurya et.al. (2023). By adopting practices that increase soil cover and reduce soil disturbance, farmers can help mitigate the effects of climate change on soil erosion. Overall, the potential impacts of climate change on soil erosion rates are significant and warrant further study. By understanding the complex interactions between climate, land use, and soil erosion, effective strategies can be developed to mitigate the negative effects of climate change on soil health and agricultural productivity.

4. Conclusion

The Himalayan watersheds are geo-dynamically unstable due to high seismic sensitivity of the area, presence of faults and nappes, high absolute height and high relative relief and steep slopes. These watersheds as ecosystems are very sensitive and fragile. The orographic and seasonal monsoon rainfall over weak structures contributes in high rates of soil erosion and landslides. Geospatial technologies especially remote sensing and GIS play a significant role in making assessment related to hydrological and morphometric parameters especially of watersheds in these highland areas. These data acquisition and processing techniques help not only in the calculation of drainage density but also the assessment of the degree of soil erosion potential in different parts of the watershed. As drainage density is function of geology, topography, climate, edaphic, vegetation and anthropogenic factors it is easy to overlay these themes and do modeling in GIS environment. In Sarbari Khad watershed the drainage density is in the range of high to very high and consequently the soil erosion degree ranges mainly from severe to catastrophic. These levels of soil erosion call for watershed management approach in this study area. Watershed management implies a rational utilization of local resources especially soil, water and forest for optimum production that too with minimum hazard to natural resources or the environment.

Conflict of interest:
The authors declare no conflict of interest.

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