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Prioritization of watersheds for land and water management in lower Sutlej River Basin using geospatial technology

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ABSTRACT

Watershed prioritization involves assessing various sections within a river basin to determine their requirements for effective land and water resource planning and management. To achieve economic effectiveness and technical efficiency, decision-makers need to allocate investments optimally to the most critical watersheds. Therefore, the goal of this study is to evaluate the Sub-Watershed Prioritization Tool (SWPT), a user-friendly GIS tool that uses Python programming language, in the Lower Sutlej River Basin for watershed prioritization. The study analyzed morphometric and topo-hydrological factors and was designed to automatically identify watersheds with critical and priority status through geospatial and statistical analysis. The river basin, having an area of 8577 km^2, was delineated into fourteen watersheds (WS1 to WS14) using the SWAT model. The ALOS PALSAR DEM, ArcGIS10.4 a, and SWPT were utilized to evaluate the morphometric and topo hydrological factors of the delineated watersheds. The priority ranks to the watersheds were assigned as compound parameter value (CPV), which was calculated by weighted sum analysis. Watersheds with the lowest CPV were given the highest priority rating, and vice versa. Based on the results WS9 was assigned the first rank whereas WS5 was assigned the 14th rank. Hence, WS9 needs immediate attention for the management of land and water resources. A modern tool such as SWPT can replace time-consuming morphometric and topo-hydrological factors for watershed prioritization. It is important to implement appropriate soil and water management measures in the highly prioritized watershed (WS9) through the study. Geospatial technology-based prioritization of watersheds (based on morphometric and topo-hydrological factors) has great potential to support land and water conservation strategies.

Keywords: Geospatial technology, morphometry, watershed prioritization, river basin

INTRODUCTION

In many developing nations, the decision-making process for the planning and management of watersheds is frequently challenging. This challenge arises due to constraints on human resources and financial budgets, coupled with the high costs and time-intensive nature of carrying out these activities (Fan and Shibata, 2014; Kim and Chung, 2014; Rahmati *et al*., 2016).) The consensus among most scientists is that watersheds constitute the most suitable landscape unit for in-depth analysis, especially concerning the planning and management of land and water resources. Regrettably, over the past few decades, watersheds have experienced degradation or face the risk of impairment due to human activities and the influence of climate change caused by human actions (Yadav *et al*., 2018). Sub-watershed prioritization stands as a fundamental principle in achieving integrated and effective watershed management. This approach aids in mitigating issues like soil erosion, floods, and sediment loads, while also identifying sub-watersheds of utmost concern to attain sustainable development goals (Chowdary *et al.*, 2013; Altaf *et al.*, 2014; Fan and Shibata, 2014). Remote sensing (RS) and Geographical Information Systems (GIS) are particularly advantageous for analyzing drainage patterns within catchments and sub-catchments, as well as for flood management and water resource modeling (Miller & Kochel, 2010; Bali *et al.*, 2012). These technologies are efficient, time-saving, and well-suited for comprehensive 3-dimensional planning due to their capacity to handle intricate challenges and extensive datasets related to change and restoration (Kumar *et al.*, 2016). The application of RS and GIS systems in geomorphological mapping has led to more objective and successful landform segmentation, measurement, and classification. Numerous studies (Magesh *et al.*, 2011; Bhagwat *et al.*, 2011; Magesh *et al.*, 2013; Singh *et al.*, 2013; Magesh & Chandrasekar, 2014; Das, 2014; Sujatha *et al.*, 2015; Kumar *et al.*, 2017; Rai *et al.*, 2017a; Rai *et al.*, 2017b; Rai *et al.*, 2018; Kandpal *et al.*, 2018; Prabhakaran & Raj, 2018; Gaikwad *et al.*, 2018, Malik *et al.*, 2019; Singh *et al.*, 2021; Sharma *et al.,* 2023) underscore the significance of RS and GIS techniques. Using GIS to assess morphometric parameters offers a viable means to characterize the hydrological response behavior of watersheds (Rai *et al.*, 2017). RS and GIS have emerged as pivotal scientific tools for the detection and analysis of natural resources, finding frequent application in soil resource characterization (Srivastava & Saxena, 2004) and prioritizing watershed activities (Suresh *et al.*, 2004). Beyond researching the morphometry of river basins, RS and GIS can be effectively employed to strategize the optimal utilization of surface runoff, contributing to the sustainable development of river basins, particularly those reliant on monsoon patterns (Mangan *et al.*, 2019).

However, among the previously mentioned studies, the Weighted Sum Analysis (WSA) introduced by Aher *et al.* (2014) emerges as a notably effective approach for prioritizing sub-watersheds within regions where data is limited or where gauging is absent. The method (WSA) focuses on utilizing morphometric parameters related to relief, area, and linear aspects for the prioritization of sub-watersheds, relying solely on digital elevation models (DEMs). The assessment of morphometric characteristics holds particular importance in the context of sustainable land and water resource preservation, especially within developing nations constrained by a lack of comprehensive quantitative data and allocated budgets for integrated watershed management (Avinasha *et al.*, 2011; Thomas *et al.*, 2011; Prasannakumar *et al.*, 2013; Sujatha *et al.*, 2014; da Silva *et al.*, 2017; Sharma *et al.*, 2023). Adhami and Sadeghi (2016) emphasize that factors related to topo-hydrology and geomorphometry play a pivotal role in determining suitable locations for implementing land and water conservation measures within sub-watersheds. These factors provide invaluable insights into the evolution of catchments and their influence on the development of drainage morphometry (Bali *et al.*, 2012; Patel *et al.*, 2013; Sujatha *et al.*, 2014). Previous research published in north-western India on morphometric analysis and prioritization of distinct watersheds has been published on the Shivalik foothills by Bhatt *et al.* (2007); Kumar & Kushwaha (2013); Kaur *et al.* (2014); Singh *et al.* (2016); Kushwaha *et al.* (2016); Kushwaha & Bhardwaj (2017); Sushanth & Bhardwaj (2019); Singh *et al.* (2021); Singh *et al.* (2023). The lower Sutlej sub-basin is currently facing multiple challenges, including soil erosion by water in upstream watersheds as highlighted by Sharma *et al.* (2023), degradation of water quality as indicated by Setia *et al.* (2020), groundwater depletion, and the impacts of climate change, as studied by Kaur *et al.* (2022). Within the study area, numerous watersheds prone to erosion are significantly impacted, adversely affecting the Sutlej River's carrying capacity and water quality. It is essential to prioritize these erosion-prone watersheds to facilitate the implementation of targeted strategies for land and water resources management, an aspect emphasized by Sharma *et al.* (2023). Up to now, there has been limited address regarding the inclusion of topo-hydrological factors, such as the topographic wetness index (TWI), stream power index (SPI), and sediment power index (STI), in the process of prioritizing watersheds. It's noteworthy that no prior research in the study area has simultaneously addressed the aforementioned parameters for these specific prioritization objectives.

Recognizing the significance of analyzing morphometric and topo-hydrological factors in watersheds, this study was undertaken to explore the following objectives: (i) assess the morphometric characteristics of fourteen watersheds within the Lower Sutlej River basin, and (ii) establish a prioritization scheme for effective land and water resource management based on morphometric and topo-hydrological factors using SWPT tool.

MATERIAL AND METHODS

Study area

The study was conducted within the lower Sutlej Sub-basin of Indian Punjab, situated between latitudes 30°39′17″ to 31°39′15″ N and longitudes 75°04′37″ to 76°48′01″ E (Fig. 1). The major land use and cover types in this area include Agriculture (73.3%), Settlement (13.6%), Vegetation (11.1%), Waterbody (1.0%), Scrub (0.66%), and Bare ground (0.24%) (Sharma *et al.,* 2023b). Agriculture dominates the region's land usage due to its significance as the primary occupation. The river basin has been delineated into fourteen watersheds using the SWAT model (Sharma *et al.,* 2023). The stream order, along with watersheds of the lower Sutlej River basin is depicted in Fig. 2. The basin's landscape comprises flat Punjab plains, largely consisting of Pleistocene and recent alluvium deposited by the Indo-Gangetic rivers. While most of the basin is covered by quaternary sediments, the

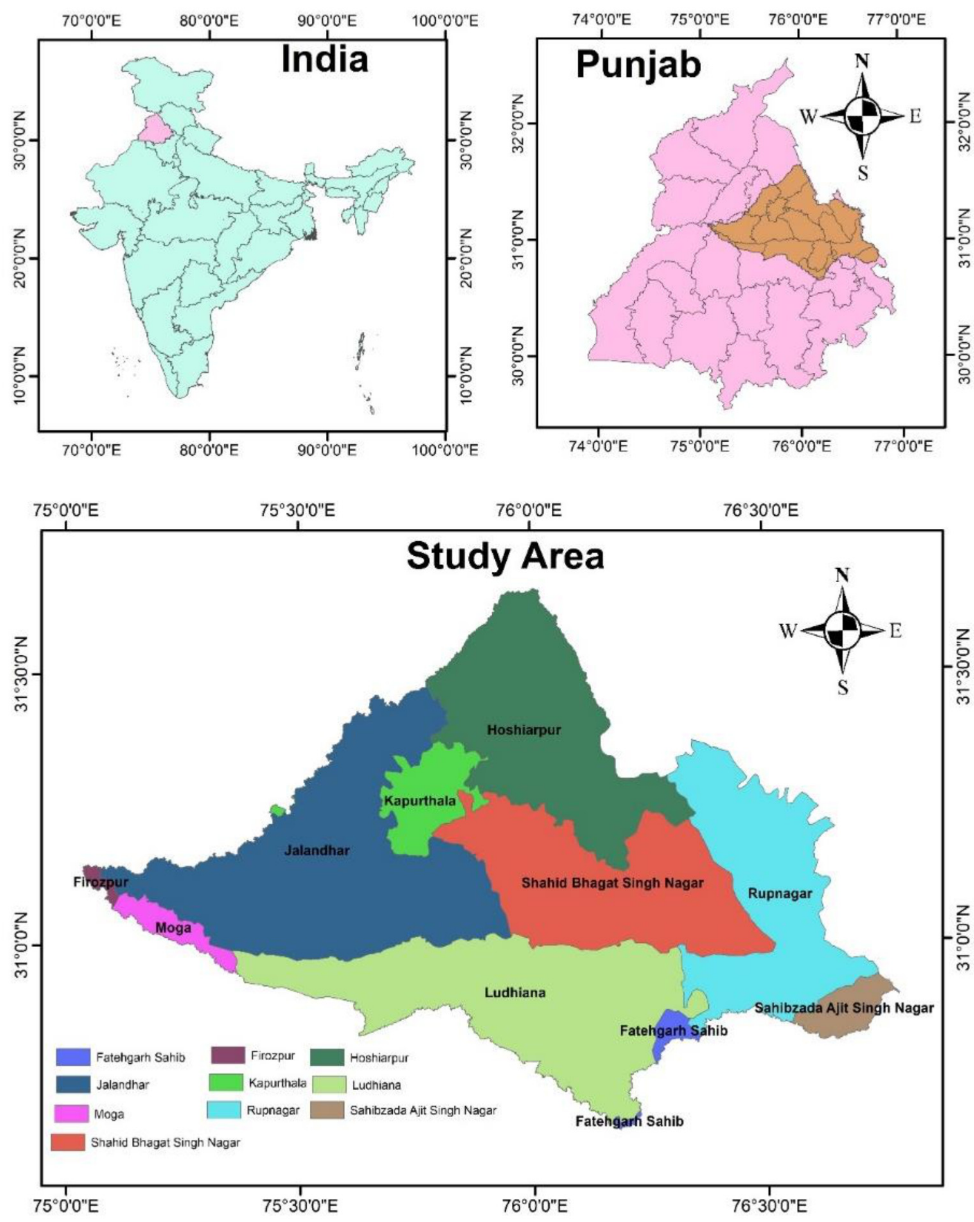

Fig. 1. Location of the Lower Sutlej River basin, Punjab, India

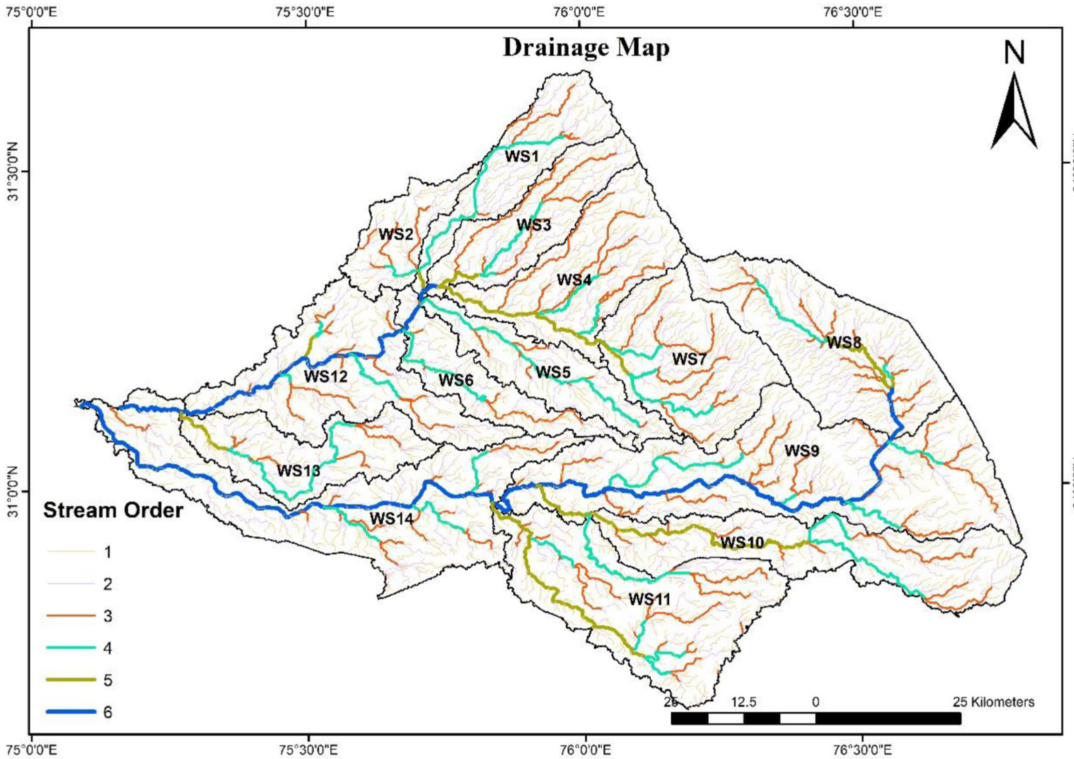

Fig. 2. Drainage network of the study area

Kandi region is primarily characterized by Neogene sedimentary rocks as shown in Fig. 3. The study area encompasses ten districts of Punjab state: Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Moga, Shahid Bhagat Singh Nagar, Sahibzada Ajit Singh Nagar, Ferozpur, Fatechgrah Sahib and Rupnagar. The climate is semi-arid and characterized by a hot subtropical monsoon, with distinct seasons of cold winters and hot summers. Influences from the Himalayas in the north and the 'Thar' desert of Rajasthan in the south and southwest are significant. The average annual rainfall was 873.78 mm, displaying notable spatial and temporal variability. The monsoon season (July to September) contributes to about 75% of the total annual rainfall. The study area spans approximately 8577 km^2, extending up to the Harike Barrage downstream of Bhakra dam, marking the confluence of the Sutlej and Beas rivers. The most prevalent soil textures in the basin include sandy loam, loam, and clay. According to Fig. 4 slope within the study watershed varied between 0 to more than 30%. The slope is proportional to runoff velocity, which determines how long rainfall takes to reach the river beds that make up the river basin's system (Villela & Mattos, 1975). Slope maps are used for numerous purposes, such as planning settlements, agriculture, deforestation and reforestation, water collection plans, engineering constructions, and morphological conservation in watersheds (Sreedevi *et al.*, 2005). The presence of the Shivalik foothills in the northern and eastern parts of the area contributes to the steeper slopes. These elevated slopes render this particular region susceptible to soil erosion, a concern accentuated by previous studies (Yousuf *et al.*, 2022; Sharma *et al.*, 2023). Due to the rapid runoff from sloped terrain, erosion is more pronounced, and opportunities for groundwater recharge are limited.

Methodology

For this study, the Sub-watershed Prioritization Tool (SWPT), an automated and user-friendly extension developed and validated by Rahmati *et al.* (2019), was employed. The SWPT is designed to evaluate and categorize sub-watersheds, highlighting those of utmost importance. By analyzing morphometric and topo-hydrological factors derived from DEMs, the tool generates these evaluations automatically. Its utilization aids decision-makers in pinpointing crucial sub-watersheds necessitating strategic soil and water conservation interventions

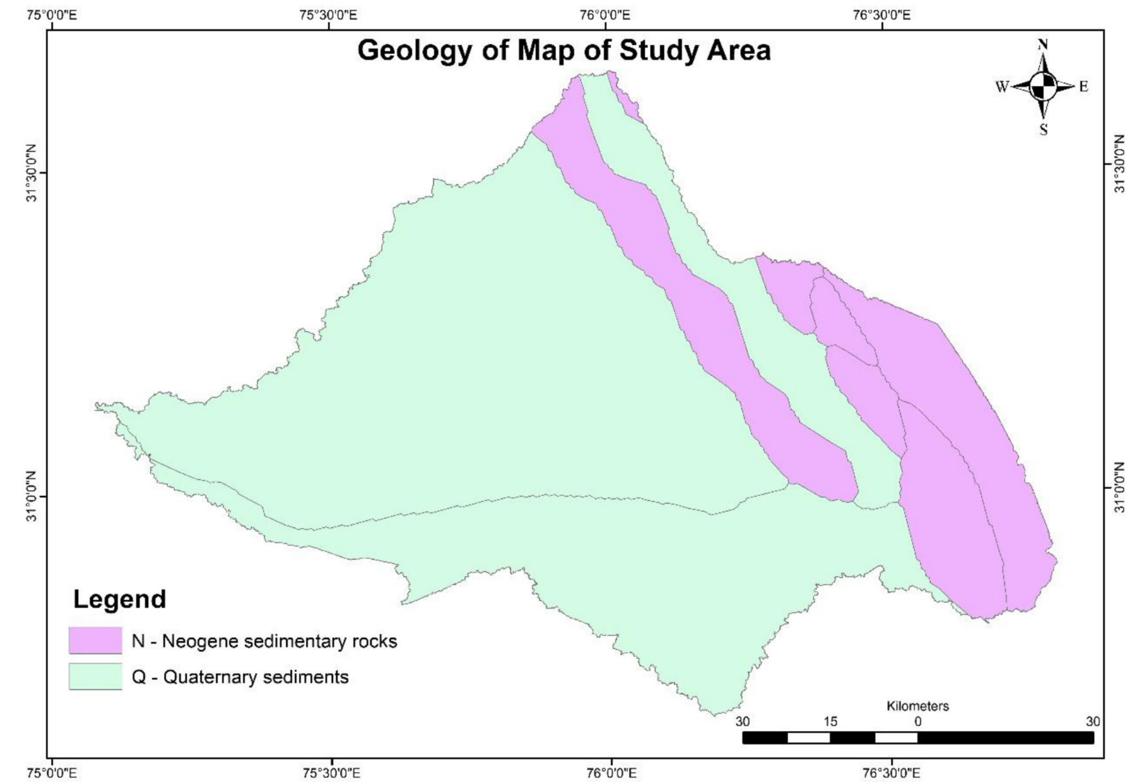

Fig. 3. Geology of Lower Sutlej River basin

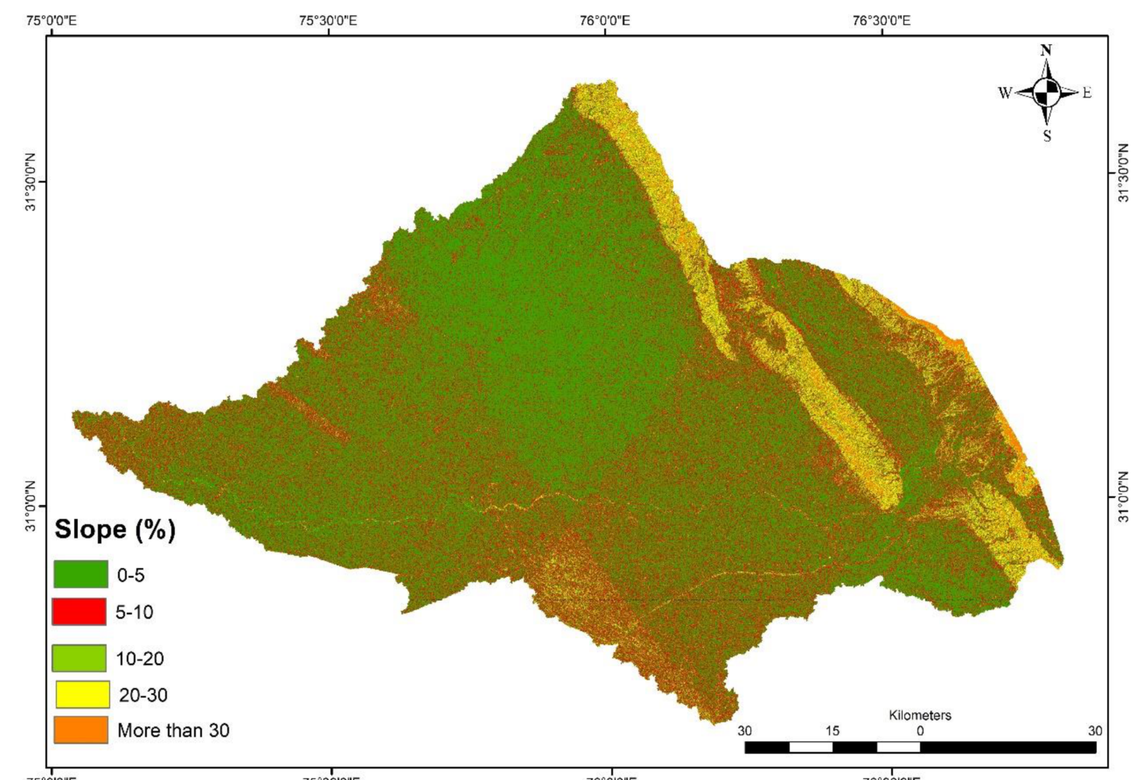

Fig. 4. Slope of the Lower Sutlej River basin

(Aher *et al.*, 2014). SWPT was incorporated into the ArcToolbox as an extension for the ArcGIS 10.4 software. A depiction of the SWPT conceptual architecture is presented in Fig. 5. For the current study, morphometric and topo-hydrological parameters were derived from the ALOS PALSAR DEM with a resolution of 12.5 m. Prioritizing watersheds was based on morphometric and topo-hydrological parameters including: (1) Areal aspects (drainage density (D), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio (Rc), constant of channel maintenance (C), elongation ratio (Re), and compactness coefficient (Cc)); (2) Linear aspects (bifurcation ratio (Rb)); and (3) Topo-hydrological factors (topographic wetness index (TWI), stream power index (SPI), and sediment transport index (STI). To ensure the appropriate ranking of hydrological units, this study adopts the WSA approach originally introduced by Aher *et al*. (2014). The WSA method integrates rigorous statistical techniques with geospatial technologies to determine the optimal combination of parameters for analysis. To mitigate potential individual biases related to various morphometric and topo-hydrological factors, the WSA technique calculates the relative significance of each parameter through statistical correlations. Additionally, it assigns weights to individual parameters based on their inherent importance (Equation (1)) as outlined by Aher *et al*. (2014):

$$\text{Prioritization} = \sum_{i=1}^{n} Wi \times Xi \tag{1}$$

Where,

Wi = Weight of each morphometric parameter calculated by the WSA approach

Xi = Value of morphometric parameters.

The mentioned approach can effectively identify the efficiency of factors by assessing their impacts separately (Rahmati *et al*., 2019)

Hydro-geomorphometric analysis

This analysis encompasses two categories of factors: morphometric factors and topo-hydrological factors. Morphometric factors comprise variables like drainage density (D), stream frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio (Rc), constant of channel maintenance (C), elongation ratio (Re), compactness coefficient (Cc), and bifurcation ratio (Rb). On the other hand, topo-hydrological parameters encompass topographic wetness index (TWI), stream power index (SPI), and sediment transport index (STI). TWI is a hydrological parameter used to characterize the wetness conditions of a landscape or terrain. It quantifies the potential for water accumulation and movement across a topographic surface. It is commonly employed in hydrological and ecological studies to understand soil moisture, surface runoff, and the distribution of wetland areas. The TWI is

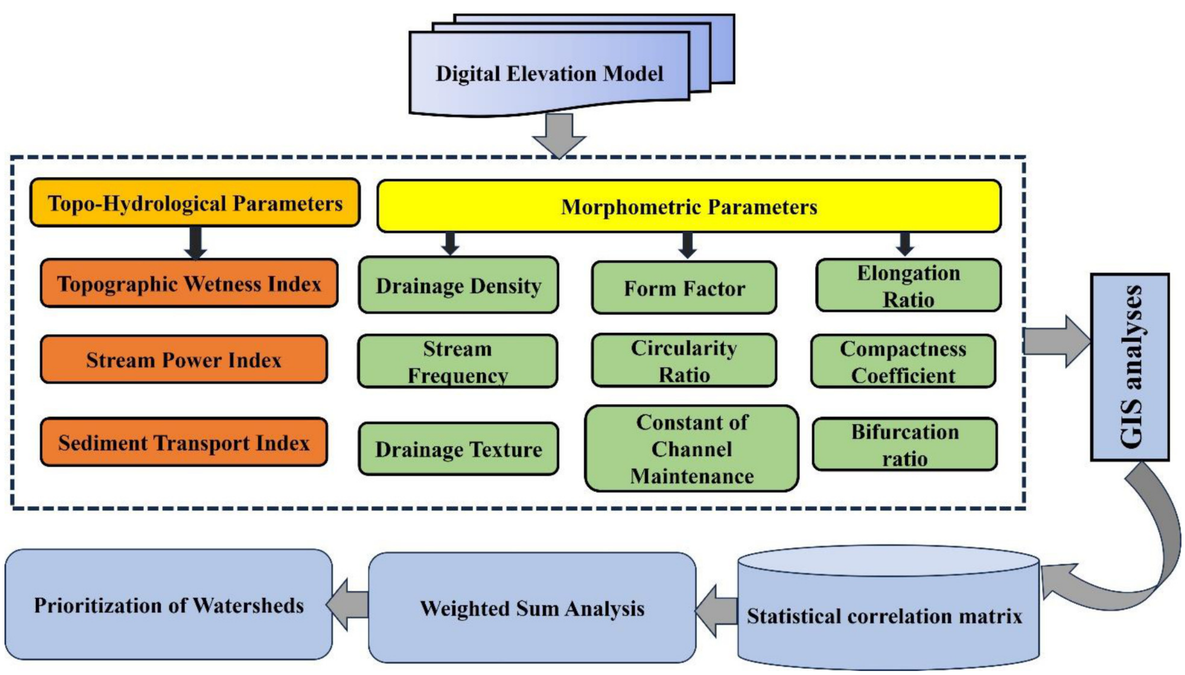

Fig. 5. Processing steps flow chart for prioritizing watersheds

derived from DEMs by considering the contributing area and slope. The contributing area represents the upslope contributing area that drains into a particular location, while the slope indicates the steepness of the terrain. The SPI is a parameter used to quantify the erosive power of flowing water within a river or stream channel. It provides a measure of the potential for sediment transport and erosion by considering the channel's slope and water discharge. The SPI is commonly used in geomorphology, hydrology, and river engineering studies to assess the erosional dynamics of streams and rivers. The STI is a metric used to assess the potential for sediment transport within a river or stream channel. It considers factors such as channel slope, discharge, sediment size, and sediment supply. The STI helps estimate the transport capacity of a stream or river and provides insights into the erosional dynamics and sediment transport potential. Both sets of factors are integrated into the design of the SWPT tool, enabling the prioritization of watersheds for targeted interventions. Utilizing a DEM with a pixel size of 12.50 meters, the study area's morphometric and topo-hydrological factors were extracted for each watershed. The SWPT extension tool facilitated the automated computation of these factors. Morphology and topo-hydrology parameters were computed using the methodology given in Table 1.

Prioritization of watersheds

To prioritize the watersheds within the study area, the SWPT tool was employed to compute correlation coefficients between pairs of morphometric and topo-hydrological factors automatically. A correlation matrix was then

Table 1. Morphology and topo-hydrology parameters were computed using the following methodology

S. No.	Parameters	Formula	Reference
1	Stream frequency (Fs)	Fs = Nu/A where Nu is the total number of stream segments of order 'u' and A is the area enclosed within the boundary of the watershed divide (Basin area)	Horton (1932)
2	Compactness constant (Cc)	$Cc= 0:2821P/A^{0.5}$ where P is the length of the watershed divide that surrounds the basin (Basin perimeter)	Horton (1945)
3	Constant of channel maintenance (C)	C = 1/D where D is drainage density	Schumm (1956)
4	Bifurcation ratio (Rb)	Rb = Nu/Nu+1 where Nu+1 is the number of segments of the next higher-order	Schumm (1956)
5	Drainage density (D)	D =Lu/A where Lu is the total stream length of order' u'	Horton (1932)
6	Elongation ratio (Re)	$Re= \sqrt{4 \times A/Pi/Lb}$ where Lb is the distance between the outlet and the farthest point on the basin boundary (Basin length)	Schumm (1956)
7	Circularity ratio (Rc)	$Rc= 4\times Pi \times A/P^2$ where P is the length of the watershed divide that surrounds the basin (Basin perimeter)	Miller (1953)
8	Form factor (Rf)	$Rf = A/Lb^2$ where Lb is the distance between the outlet and the farthest point on the basin boundary (Basin length)	Horton (1932)
9	Drainage texture ratio (Rt)	Rt = Nu/P	Horton (1945)
10	Topographic wetness index (TWI)	$TWI = \ln(As / \tan \beta)$ Where: As = Upslope contributing area β = Slope in radians	Beven and Kirkby (1979)
11	Stream power index (SPI)	$As \times \tan \beta$	Whipple and Tucker (1999)
12	Stream transport index (STI)	$STI =(m+1) \times As/22:13^m \times sinb/0:0896^n$ where b is the local slope gradient in degrees, m is the contributing area exponent, and n is the slope exponent	Moore and Burch (1986)

generated, aiding in determining the factors that contribute to prioritization (Rahmati *et al*., 2019). For this study, factors with correlation coefficients exceeding 0.6 were chosen for consideration. Using these selected factors, the SWPT tool calculates the WSA index, which in turn establishes the prioritization of watersheds. The tool arranges watersheds in descending order, with the most vulnerable to runoff generation and soil erosion ranking first as number 1, and the least susceptible one placed at the bottom of the list.

RESULTS AND DISCUSSIONS

Geomorphometric characteristics

The outcomes of geomorphometric parameters, obtained through the utilization of an automated GIS-based SWPT, are presented in Table 2. Stream frequency (F_s) measures the ratio between the total number of streams in a basin area and the total number of streams (Horton, 1932). Fs are classified as very high (20–25), high (15–20), moderately high (5–10), moderate (10–15), and low (0–5) (Venkatesan, 2014). The texture of the drainage network is replicated by stream frequency, which is typically decided by the lithology of the basin. The basin's F_s value has a positive association with the area's drainage density value, showing that stream number increases as drainage density increases. It can be observed that the stream frequency (Fs) varies between 0.00000125 (WS5) and 0.0000000857 (WS9). A bifurcation ratio (R_b) is the number of stream segments of order U divided by the number of stream segments of the next higher-order (U+1) (Strahler, 1964). It is determined by the watershed's physiographic features, slope, and climate. Stream integration in a drainage basin is determined by R_b, a dimensionless parameter that takes account of different orders of flow in the basin and normally ranges from 3.0 to 5.0. It indicates the geological and tectonic properties of a watershed and can be used to predict various elements of a river basin (Sharma *et al*., 2015). The lower the R_b value, the less structurally disturbed or partially disturbed the catchment has been (Verstappen, 1983), with no drainage pattern distortion due to geological or structural control (Chopra *et al*., 2005). A circular basin with high infiltration capacity and fewer streams in the catchment has a lower R_b. As R_b increases, flood damage is more likely to occur (McCullagh, 1978), indicating high overland flow with greater soil erosion and poor sub-catchment recharge. A greater R_b value implies an early peak in a hydrograph, indicating the possibility of flash flooding during rainfall storms (Hajam *et al*., 2013). Bifurcation ratio (R_b) results indicate the highest value in WS2 (3.201), while the lowest is found in WS7 (1.390). The basin area divided by basin length is called the form factor (R_f) (Horton, 1945). The R_f for a fully round basin would always be larger than 0.78. The lower values of R_f indicate a long basin shape. A watershed with a greater R_f value achieves a peak runoff rate/flow in a small period, whereas a watershed with a lower R_f value results in a flow for longer periods with a flatter peak (Waikar & Nilawar, 2014). Regarding the R_f, SWPT results reveal the highest value in WS7 (0.529) and the lowest in WS14

Table 2. Morphometric and topo-hydrological parameters of the watersheds

Watershed Name	Parameters											
	Fs ($\times 10^{-6}$)	Rb	Rf	Re	Rc	D	Rt	Cc	C	TWI	SPI	STI
WS1	0.2416	2.558	0.333	0.651	0.108	0.001	0.000	3.040	1212.98	9.910	3.567	9.124
WS2	0.880	3.201	0.301	0.619	0.130	0.001	0.001	2.771	843.99	10.528	3.244	8.576
WS3	0.267	2.213	0.220	0.529	0.143	0.001	0.001	2.648	1222.64	10.202	3.334	9.136
WS4	0.295	2.122	0.467	0.771	0.139	0.001	0.001	2.678	1164.36	10.061	3.462	9.103
WS5	0.25	2.309	0.497	0.796	0.071	0.001	0.002	3.764	774.63	10.495	3.190	8.341
WS6	0.5297	2.890	0.157	0.447	0.062	0.001	0.001	4.004	1257.35	10.414	3.185	8.349
WS7	0.152	1.390	0.529	0.820	0.214	0.001	0.000	2.160	1576.95	9.933	3.491	9.207
WS8	0.112	1.960	0.299	0.617	0.187	0.001	0.000	2.309	1902.82	9.710	3.634	9.259
WS9	0.857	2.383	0.166	0.460	0.089	0.000	0.000	3.347	2442.65	9.877	3.576	9.338
WS10	0.326	1.893	0.459	0.764	0.080	0.001	0.001	3.531	1246.05	10.094	3.416	8.876
WS11	0.215	1.861	0.368	0.685	0.117	0.001	0.001	2.926	1638.75	10.336	3.416	9.243
WS12	0.153	1.452	0.219	0.528	0.074	0.000	0.000	3.669	2223.78	10.381	3.265	8.917
WS13	0.393	2.854	0.206	0.512	0.100	0.001	0.001	3.156	1318.15	10.387	3.219	8.477
WS14	0.1124	2.438	0.128	0.404	0.056	0.000	0.000	4.233	2291.42	10.365	3.271	9.207

(0.128). The ratio of the diameter of a circle with the same area as the basin to the maximum basin length is known as the elongation ratio (R_e) (Horton, 1945; Miller, 1953; Schumm, 1956). It is one of the most significant parameters to consider while analyzing the geometry of a watershed because it has an impact on stream characteristics (Strahler, 1968). A circular river basin outperforms an elongated basin in terms of surface runoff discharge (Singh & Singh, 1997). Drainage basins in dry and semi-arid climates have R_e values of <0.50, 0.50 to 0.75, and >0.75, respectively, for tectonically active, moderately active, and passive situations (Sarma *et al.*, 2015). A lower R_e value implies severe erosion and sediment load susceptibility, while a higher Elongation ratio value suggests strong infiltration capacity with minimal runoff (Reddy *et al.*, 2004). The geometry of a watershed concerning R_e can be classified as very elongated (0.5), elongated (0.5 to 0.7), less elongated (0.7 to 0.8), oval (0.8 to 0.9), and circular (0.9 to 0.10) (Pareta & Pareta, 2011). It can be observed that the R_e varies between 0.404 (WS14) and 0.820 (WS7). The watershed area to the area of a circle with the same perimeter as the watershed is known as the circularity ratio (R_c) (Miller, 1953; Strahler, 1964). The watershed area to the area of a circle with the same perimeter as the watershed is known as the circularity ratio (R_c) (Miller, 1953; Strahler, 1964). A basin's circulatory ratio is affected by factors like the length and frequency of streams, basin slope, land use/land cover, climate, relief, and geological formations (Patel *et al.*, 2013). It is an essential parameter that shows the dendritic stage of watersheds. High, medium, and low R_c values represent the old, mature, and young stages of the tributary watershed's life cycle, respectively (Magesh *et al.*, 2012). R_c values of 0 and 1, respectively, suggest extremely elongated and circular forms (Sreedevi *et al.*, 2013). In terms of R_c, WS7 acquires the highest value (0.214), while WS14 holds the lowest (0.056). It is a measure of how close the channels are spaced together (Ahmed *et al.*, 2010). It calculates the segmentation of the landscape as well as the possibility for runoff (Chorley, 2019). D_d has been classified as very fine (more than 8), fine (6–8), moderately coarse (4–6), extremely coarse (2) and coarse (2–4) (Tavassol, 2016). Small relief of the basin, permeable subsurface materials, and dense vegetative conditions are indicated by lower D_d values (6.0). High D_d values (greater than 8) suggest high relief, subsurface materials that are impermeable, and limited vegetation. In connection to quick runoff in channels, such basins are determined to be particularly vulnerable to flood threats. Drainage texture (D_t) is the ratio between the sum of the segments of a stream and its perimeter (Horton, 1945) and is affected by vegetative cover, rainfall, lithology, infiltration capacity, and the relief characteristics of the basin (Sreedevi *et al.*, 2013). Smith (1950) divided the D_t into five main categories, very coarse (less than 2), coarse (2-4), moderately coarse (4-6), fine (6-8), and very fine (greater than 8). Analyzing drainage density (D_d) and drainage texture (Rt), WS5 ranks highest, and WS9 ranks lowest. The compactness coefficient (C_c) is the ratio of a circular region's perimeter to its circumference, which equals the catchment's area (Horton, 1945). It is unaffected by watershed size, although it is significantly influenced by watershed slope (Rai *et al.*, 2018). The lower the C_c number, the greater the runoff and erodibility. A basin with a C_c value of 1 is perfectly round. (Horton, 1932). Regarding the compactness coefficient (Cc) factor, WS14 exhibits the highest value (4.233), whereas WS7 showcases the lowest (2.160). The reciprocal of D_d is the constant of channel maintenance (C_{cm}) (Horton, 1945). It describes the size of landform elements in a drainage watershed (Strahler, 1957). Lower C_{cm} values indicate physical difficulties in the drainage basin in connection to greater runoff conditions and reduced permeability. The constant of channel maintenance (C) factor values position WS9 (2442.646) at the top rank and WS5 (774.634) at the bottom. Evaluating TWI, SPI, and STI, the prioritization results indicate that WS2, WS8, and WS9 attain the highest values, while WS8, WS6, and WS5 achieve the lowest values (Table 2). Higher TWI values indicate areas with potentially higher moisture levels and increased water flow, while lower TWI values represent drier areas or locations with limited water accumulation. The TWI has various applications in hydrology, including watershed management, flood prediction, soil moisture assessment, and wetland delineation. It provides valuable insights into the spatial distribution of wetness conditions within a landscape, aiding in land use planning, conservation efforts, and decision-making related to water resources management. Higher SPI values indicate greater erosive power and sediment transport potential of the flowing water. Areas with high SPI values are likely to experience more erosion, channel incision, and sediment deposition, while lower SPI values indicate reduced erosional potential. By incorporating the

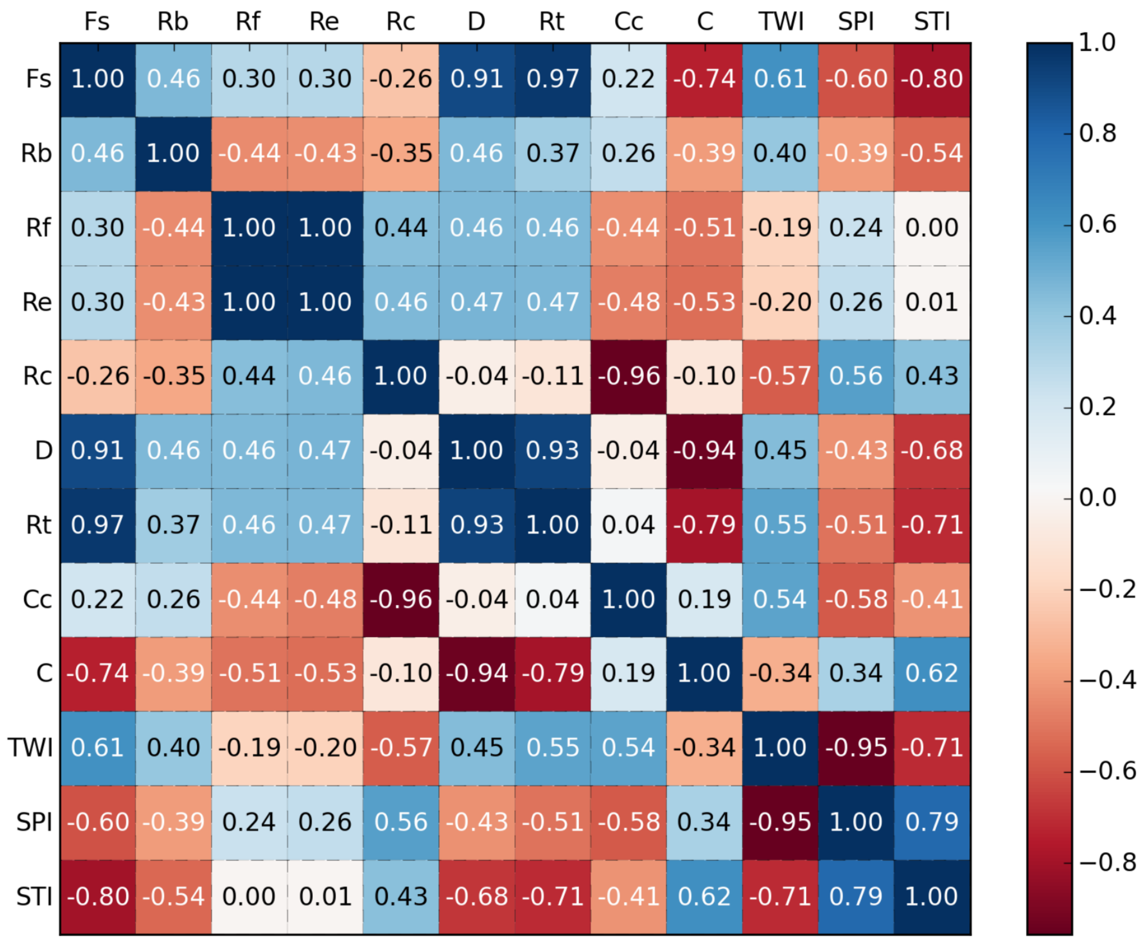

Fig. 6. Correlation matrix of morphometric and topo-hydrological parameters

SPI, researchers and practitioners can gain insights into the erosional dynamics of rivers and streams, aiding in the sustainable management of water resources, river ecosystems, and related infrastructure.

Automated prioritization of watersheds

The correlation matrix, derived through the WSA approach, for morphometric properties of watersheds, is illustrated in Fig. 6. The presented results pertain to correlation coefficients (r) with values greater than 0.6. Stream frequency (Fs) exhibits a significant positive correlation with bifurcation ratio (R_b) (r = 0.46), drainage density (D) (r = 0.91), drainage texture (R_t) (r = 0.97), and TWI (r = 0.61). However, it demonstrates a negative correlation with the Constant of channel maintenance (C) (r = -0.74), SPI (r = -0.60), and STI (r = -0.8). Form factor (R_f) is positively correlated with Elongation ratio (Re) (r = 0.99), Circularity ratio (R_c) (r = 0.44), and drainage density (r = 0.46), while it exhibits a high negative correlation with Compactness coefficient (C) (r = -0.44) and C (r = -0.51). The relationships of Drainage density (D) and Drainage texture (Rt) with other factors reveal positive associations with TWI and negative connections with Constant channel maintenance (C), SPI, and STI. TWI, on the other hand, is highly and negatively correlated with SPI (r = -0.95) and STI (r = -0.71). Despite a pronounced negative relationship with Fs, D, Rt, and TWI, SPI demonstrates a substantial positive correlation (r = 0.94) with STI. The final prioritization of watersheds is executed based on compound parameter values (CPV). The watershed with the lowest CPV takes precedence, determining the priority, followed by subsequent watersheds ranked accordingly, as outlined by Aher *et al.* (2014). CPV is calculated using the assigned weights for each morphometric parameter. The prioritization outcomes for watersheds are detailed in Table 3. WS9 attains the highest priority ranking with a CPV of -553.162. It is followed by WS14

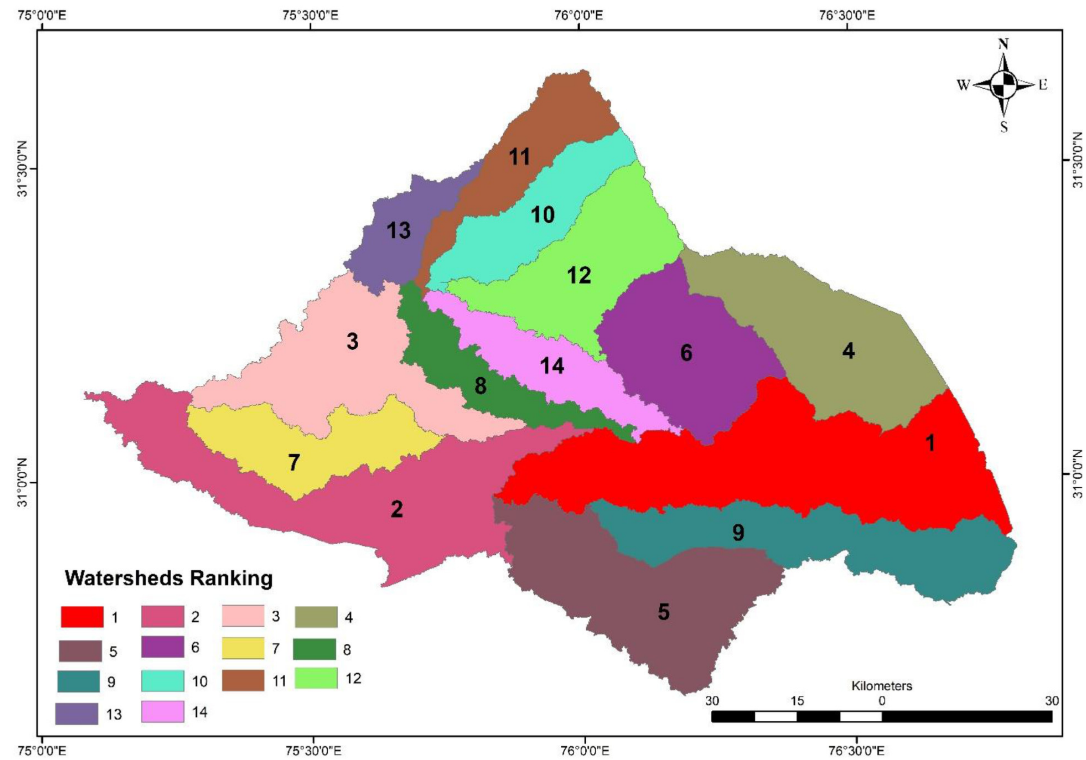

Fig. 7. Priority of watersheds based on Morphometric and Topo-Hydrological Factors

Table 3. Prioritization and final ranking of watersheds

Watershed Name	Compound Parameter Value	Priority Ranking
WS9	-553.162	1
WS14	-518.972	2
WS12	-503.586	3
WS8	-430.885	4
WS11	-371.102	5
WS7	-357.032	6
WS13	-298.523	7
WS6	-284.836	8
WS10	-282.217	9
WS3	-276.976	10
WS1	-274.772	11
WS4	-263.687	12
WS2	-191.142	13
WS5	-175.441	14

(CPV -518.972), WS12 (CPV = -503.586), WS8 (CPV = -430.885), and so on, with descending CPV values, culminating with WS5 (CPV = -175.441) (Table 3). Identification of a vital watershed is an important issue in natural resources management, especially in the context of watershed management techniques, because different watersheds have varied hydrological behaviors depending on their morphometric and topo-hydrological properties. (Jain and Das, 2010; Javed *et al.*, 2011). The final watershed priority or ranking map based on morphometric and topo-hydrological parameters of the lower Sutlej River basin is shown in Fig. 7.

CONCLUSION

Prioritizing watersheds within a larger basin is a pivotal stride toward optimizing watershed management and judiciously distributing its natural resources. Given the constraints of financial resources, human capital, and time, this process becomes particularly indispensable in regions characterized by data scarcity and limited measurement (ungauged regions),. Although various approaches have been employed for watershed prioritization, some prove inefficient, others lack applicability in specific contexts, and some require manual intervention. In this study, the methodology was adopted to establish watershed priority using a Python-based tool named SWPT as an extension of ArcGIS 10.4 software. It is time-consuming and laborious to prioritize watersheds using morpho-metrics and topo-hydrology, and SWPT can replace such methods. The order of the watershed prioritization was WS9>WS14> WS12> WS8> WS11> WS7> WS13> WS6>WS10> WS3> WS1> WS4> WS2> WS5. One of the most degraded ecosystems of India is the lower Shivaliks of north-western India, where the most prioritized watershed (WS9) is located. To identify the major problems associated with water spread, soil erosion, and aquifer recharge, a geospatial technique-based approach to watershed prioritization could be used.

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