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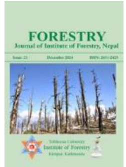


# Sub-Watershed Prioritization for Soil Conservation and Watershed Management Through Geospatial Analysis in Babai Watershed, Dang District, Nepal

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**KEYWORDS**

*Anthropogenic factors*
*Remote sensing*
*Sustainable development*
*Geospatial analysis*
*Catchment*
*Morphometric analysis*

**ABSTRACT**

As global environmental challenges such as water scarcity, soil erosion, and habitat degradation continue to escalate, the importance of effective watershed management becomes increasingly evident. Freshwater resources are under mounting pressure, particularly in regions with limited financial and technical capacities, underscoring the necessity of sustainable management practices. One essential approach to achieving this goal is sub-watershed prioritization, which plays a pivotal role in optimizing conservation efforts and resource allocation. This study focuses on prioritizing sub-watersheds within the upper region of the Babai Watershed, located in the Dang District of Nepal, through a GIS-based land use-land system morphometric analysis. The prioritization process integrates biophysical and anthropogenic factors, weighted at 60% and 40% respectively, to assess ten sub-watersheds ranging from 64 to 148 square kilometers. Among these, Gwar Khola emerged as the highest priority sub-watershed, primarily due to its high erosion potential and dense population, while Hapur Khola ranked second and Kaptine Khola ranked lowest. These results emphasize urgent need for targeted interventions in high-priority sub-watersheds, particularly in Gwar Khola, while also advocating for ongoing monitoring and management efforts across all sub-watersheds. By establishing a robust framework for effective resource allocation, this study aims to enhance the long-term resilience of the Babai Watershed, contributing to sustainable watershed management practices in the region.

## INTRODUCTION

Watersheds are typically defined as the area of land that drains to a single point on a water body, such as stream, lake or ocean, or some close variation of this language (Black, 1997). Its size can range from large regions spanning thousands of square kilometers to

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smaller, localized areas. Watersheds are crucial for conducting physical analyses and integrated management planning that takes into account both natural systems and socio-political factors (Wang et al., 2016). Within these larger systems, a sub-watershed is a smaller unit characterized by the drainage area that directs water to a specific tributary or section of a river system (Arulbalaji & Padmalal, 2020). Today, watersheds face significant challenges primarily due to human activities and climate change, which lead to widespread environmental degradation. Deforestation and changes in land use, particularly agricultural expansion, are major contributors to increased surface runoff, soil erosion, and disruptions in local hydrological cycles, all of which adversely affect water quality (Houghton, 2005). Additionally, the over-exploitation of water resources exacerbates these issues, while invasive species threaten the ecological integrity of watershed ecosystems (Postel et al., 1996). Climate change amplifies these challenges by altering precipitation patterns and increasing the frequency of extreme weather events, further compromising water availability and quality (Milly et al., 2005). The combination of steep terrain, unsustainable agricultural practices, and inadequate waste management accelerates the deterioration of water quality and increases the risk of natural disasters like floods and landslides (Jourgholami et al., 2020). These growing concerns highlight the need for targeted conservation and prioritization efforts to protect vulnerable watershed areas (Prasannakumar et al., 2011).

Sub-watershed prioritization is a vital strategy for natural resource management and mitigating the adverse effects of land degradation. It plays a crucial role in implementing soil conservation measures, particularly in areas impacted by human activities like deforestation, urbanization, and unsustainable farming practices (Biswas et al., 1999; Abdeta et al., 2020). Prioritizing sub-watersheds enables conservation efforts to focus on the areas most in need of intervention, reducing degradation and improving ecosystem services (Sharma et al., 2009). Additionally, this approach facilitates the efficient use of resources by directing attention to areas with the greatest potential for soil and water conservation, thereby optimizing the effectiveness of management strategies (Gajurel et al., 2020). Understanding the geomorphology, land use/land cover (LULC), and hydrology of a watershed is critical for grasping its dynamics (Bhattacharya et al., 2020). Traditional river morphology analysis methods can be labor-intensive and time-consuming, but advances in geospatial technologies have made such assessments more efficient and accurate (Aher et al., 2014; Mishra et al., 2018; Kadam et al., 2019). To address these challenges, various methods for watershed and sub-watershed prioritization have been developed, ranging from simple models to complex, data-heavy approaches that require careful implementation (Shekar et al., 2023). Morphometric analysis has been proven particularly useful in tackling issues related to watershed management, resource conservation, and sustainable development (Kim et al., 2005; Javed et al., 2011). Several studies have applied morphometric analysis for sub-watershed prioritization, including those by Sharma and Mahajan (2020) and Khanday and Javed (2016). In Nepal, research on watershed prioritization includes studies like Ghimire et al. (2023), which takes a geographical approach in the Himalayas, and Regmi et al. (2016), which examine soil erosion in the Phewa Lake watershed. Integrating LULC data into prioritization is essential, as it links land cover types with human land use and provides valuable insights for guiding conservation and management actions (Javed et al., 2009; Puno & Puno, 2019; Shekar & Mathew, 2022).

The Babai Watershed in Nepal faces numerous interconnected challenges primarily driven by human activities and climate change. Deforestation, unregulated grazing, excessive timber extraction, and agricultural encroachment into forested areas have led to significant land degradation, resulting in the loss of essential ecosystem services such as water retention and biodiversity preservation (Hengaju & Manandhar, 2015). Located in the Siwalik region, the watershed is highly susceptible to soil erosion and landslides due to its steep slopes and unstable geological structure, with landslide occurrences influenced by rainfall and geological conditions (Bhandari & Dhakal, 2019). Climate change is expected to exacerbate these challenges, with projections indicating increased rainfall and river flow, yet significant water shortages from January to May, which could severely affect irrigation and water availability (Mishra et al., 2021). These pressing issues underscore the urgent need for effective sub-watershed prioritization to guide conservation and development efforts in the Babai Watershed.

We have selected the land use-land system-based morphometric analysis method for sub-watershed prioritization in the upper region of Babai Watershed, as it provides an effective integration of both biophysical and anthropogenic factors. This method combines land use, land system, and population parameters to assess watershed vulnerability, making it an ideal choice for identifying priority areas for intervention. By utilizing high-resolution (≥30 m) imagery and GIS analysis, the method assigns a 60% weight to biophysical factors (land use-land systems) and a 40% weight to anthropogenic factors (population density). This approach results in a cumulative sub-watershed priority value (SWSPCV), which serves as the basis for ranking the sub-watersheds. The primary goal of this research is to evaluate and prioritize sub-watersheds in the upper region of Babai Watershed, an area increasingly impacted by climate change and human activities. The study will provide valuable insights for targeted soil conservation efforts and sustainable watershed management. The findings will help policymakers and conservation agencies allocate resources efficiently and develop location-specific interventions to mitigate land degradation. Additionally, the prioritization framework can be applied to similar watersheds, promoting adaptive management, ecosystem resilience, and guiding future research on sustainable land management practices.

## MATERIALS AND METHODS

### Study area

The Babai Watershed, located in Western Nepal, spans across three districts: Dang, Salyan, and Bardiya. It originates from the Middle Mountain Zone (MMZ) and is drained by the Babai River, which flows from east to west, starting in the Siwalik Hills. The watershed is geographically bounded by the following coordinates: 27°57′59.03″ N, 82°33′42.80″ E in the east; 28°28′30.14″ N, 81°28′30.14″ E in the west; 28°12′47.90″ N, 82°15′46.08″ E in the north; and 28°01′03.89″ N, 82°12′39.61″ E in the south, covering a total area of 1,952 square kilometers (Bhandari & Dhakal, 2020). The Watershed has a tropical to sub-tropical climate, with monsoon rains from June to September accounting for about 85% of the 1500 mm annual precipitation, and an average temperature of 27°C. (MFD, 2018; Panday, 2012). The Babai River's Chepang station records an average annual flow of 86 $m^3/s$, with a peak runoff of 257 $m^3/s$ in August and a low of 9.9 $m^3/s$ in April, while the Rani Jaruwa station reports average maximum and minimum temperatures of 31°C and 18°C, respectively (Mishra et al., 2021). The study area, situated in the Upper Region of the Babai Watershed within the Dang district, covers approximately 1,133 square kilometers. It includes five municipalities, two sub-metropolises, and three rural municipalities, with an elevation range of 471 m to 2,060 m above sea level (Figure 1).

### Dataset used

The study utilizes various datasets to analyze and prioritize sub-watersheds in the study area, incorporating high-resolution geospatial, demographic, and environmental information to evaluate watershed dynamics effectively (Table 1).

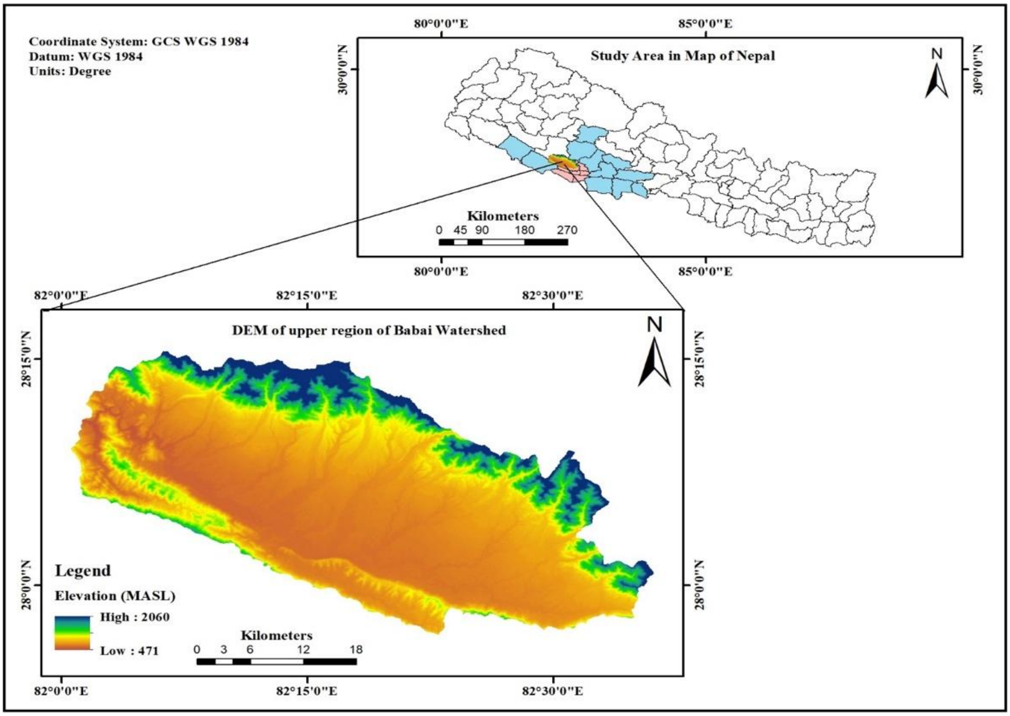


**Figure 1: Study area map with a digital elevation model**

**Table 1: Datasets used for sub-watershed prioritization**

| Datasets | Year | Sources | Resolution |
|---|---|---|---|
| LANDSAT/LC08/C02/T1_L2 | 2023 | United States Geological Survey (USGS) | 30 m |
| DEM (for Slope) | 2023 | SRTM 1 Arc-Second Global (USGS/NASA) | 30 m |
| Demographic Data | 2023 | Central Bureau of Statistics (CBS), Nepal | - |

## Data processing

Data processing transforms raw datasets into structured formats for sub-watershed prioritization. Landsat 8 OLI/TIRS C2 L2 images (30m resolution) were acquired from the USGS Earth Explorer and underwent radiometric and geometric corrections, including cloud masking and image enhancement, to improve image quality by minimizing cloud cover and distortion. The Digital Elevation Model (DEM) data from the SRTM 1 Arc-Second Global, also downloaded from the USGS Earth Explorer, were processed to remove surface depressions and generate a slope map. Land Use Land Cover (LULC) classification was performed using the Maximum Likelihood algorithm and verified with high-resolution Google Earth images (2023) to ensure accuracy. Additionally, population data for the study area were sourced from the 2078 census by the Central Bureau of Statistics (CBS, 2023). The data were processed to estimate sub-watershed population density through spatial joins and overlay analyses.

**Determination of erosion condition**

**Land use erosion potential (LUEP) areas:** A slope map is generated from DEM data using ArcGIS 10.8 software. Following Sthapit (1998), the Land Use Erosion Potential (LUEP) map is prepared by classifying areas as high, moderate, or low erosion potential based on slope gradient. Slopes greater than 30° are classified as high, those between 5° and 30° as moderate, and slopes less than 5° as low erosion potential.

**Land system erosion potential (LSEP) areas:** A Land Use/Land Cover (LULC) map for 2023 is created by classifying Landsat imagery using the Maximum Likelihood Supervised Classification algorithm in ArcGIS 10.8. Based on Sthapit's (1998) method, a Land System Erosion Potential (LSEP) map is prepared by classifying areas as high, moderate, or low erosion potential. Agricultural Land, Barren Land, and Riverside are classified as high erosion potential, Open Forest, Rangeland, and Lakes as moderate, and Close Forest and Built-up Areas as low erosion potential.

**Sub-watershed delineation**

Sub-watersheds are delineated in ArcGIS using a 30-meter resolution DEM from USGS. After filling surface depressions, the flow direction and flow accumulation tools are applied. A raster calculator is used to identify streams with more than 5000 pixels, creating a file "flow_accumulation_raster 5000.tif." The watershed tool generates the sub-watershed raster, and pour points are marked at watershed outlets. The raster-to-polygon tool converts the raster into polygons, and sub-watersheds are divided based on major streams and local administrative boundaries, such as Sub-Metropolitan Cities and Rural Municipalities.

**Sub-watershed prioritization**

Sub-watersheds are prioritized using ArcGIS analysis, with biophysical and anthropogenic (population density) factors weighted at 60% and 40%, respectively. The higher weight for biophysical factors highlights the importance of erosion risk in conservation efforts, while the inclusion of population density integrates human pressures on natural resources.

**Biophysical characteristics**

Erosion potential is assessed using the Land Use Erosion Potential (LUEP) map and the Land System Erosion Potential (LSEP) map. The LUEP map classifies erosion risk as high (H), moderate (M), or low (L), while the LSEP map assigns high (h), moderate (m), or low (l) erosion potential areas. Both the maps are overlaid to create an Erosion Potential Classification (EPC) map. Double-letter symbols are simplified into single-letter codes (H, h, M, L, l) for more effective erosion risk assessment and management. The conversion table (Table 2) standardizes these symbols, with "H" indicating very high, "h" high, "M" moderate, "L" low, and "l" very low erosion potential.

**Table 2: Conversion table of double letter symbols of erosion potential to single letters**

| Land Use Erosion Potential | Land System Erosion Potential | | |
|---|---|---|---|
| | High (h) | Medium (m) | Low (l) |
| High (H) | Hh = H | Hm = h | Hl = M |
| Medium (M) | Mh = h | Mm = M | Ml = L |
| Low (L) | Lh = M | Lm = L | Ll = l |

H = Very High, h = high, M = Moderate, L = Low, l = very low

Erosion severity for each sub-watershed is quantified using the Land Use Land System Erosion Potential Value (LULSEPV):

$$LULSEPV = \frac{\{(Very\ high\ area * 8) + (high\ area * 6) + (moderate\ area * 4) + (low\ area * 2) + (very\ low\ area * 1)\}}{Total\ area\ of\ the\ sub\ watershed} \ldots\ldots (1)$$

The Sub-Watershed Biophysical Value (SWSBPV) is calculated to scale LULSEPV between 1-60:

$$SWSBPV = \frac{(LULSEPV - 1) * 60}{(Highest\ LULSEPV - 1)} \ldots\ldots (2)$$

**Population characteristics**

Population density is estimated using CBS (2023) data and integrated into sub-watershed prioritization. It is calculated as:

Average Population Density

$$APD = \frac{Total\ population\ of\ watershed}{Total\ area\ of\ watershed} \ldots\ldots (3)$$

By overlaying district and sub-watershed boundaries, population data are assigned to each sub-watershed. The population density for each sub-watershed is determined as:

Sub-watershed Population Density

$$PD = \frac{Total\ population\ of\ sub-watershed}{Total\ Area\ of\ that\ Watershed} \ldots\ldots (4)$$

Sub-watershed population density numerical values (SWSPDNV) are computed as follows:

- If PD < APD:

$$SWSPDNV = \frac{PD}{APD} * 20 \ldots\ldots (5)$$

- If PD > APD:

$$SWSPDNV = \left(\frac{PD - APD}{HPD - APD} * 20\right) + 20 \ldots\ldots (6)$$

Where,

PD = Population Density of the Sub-watershed

HPD = Highest Population Density of Sub-watershed

APD = Average Population Density of Upper Region of Babai Watershed

**Final prioritization**

The Sub-Watershed Priority Cumulative Value (SWSPCV) is calculated by combining SWSBPV and SWSPDNV:

$$SWSPCV = SWSBPV + SWSPDNV \ldots\ldots (7)$$

Sub-watersheds are ranked based on SWSPCV, with higher values indicating greater priority ranking.

## RESULTS

**Erosion condition assessment**

The erosion condition of the upper region of the Babai Watershed was assessed based on two indicators: Land Use Erosion Potential (Slope Analysis) and Land System Erosion Potential (LULC Analysis). The results from the slope and land use/land cover (LULC) analysis are presented below.

**Land use erosion potential (LUEP) areas:** The slope analysis revealed that majority of the watershed area (60.47%) exhibits low erosion potential, covering approximately 685.67 square kilometers. Moderate erosion potential areas occupy 431.96 square kilometers (38.09%), while high erosion potential areas cover only 16.16 square kilometers (1.42%). The slope map (Figure 2) clearly illustrates that high-erosion-potential areas are concentrated in hilly and mountainous regions, whereas low-erosion-potential areas are more prevalent in lowland and flat terrains.

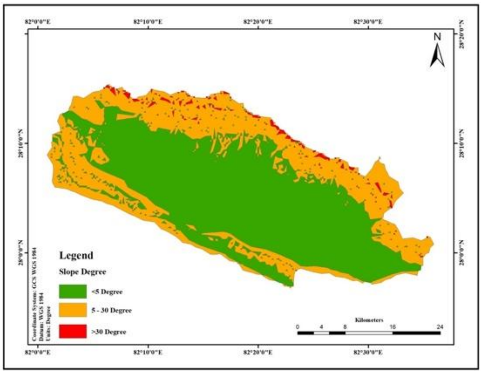


**Figure 2: Slope map of upper region of babai watershed**

**Land system erosion potential (LSEP) areas:** The land use/land cover (LULC) analysis of the study area, as shown in the LULC map (Figure 3), reveals that close forest is the dominant land class, covering 587.54 square kilometers (51.82%) of the total area. This is followed by agricultural land at 340.58 square kilometers (30.04%) and built-up areas at 109.12 square kilometers (9.62%). Other land classes include open forest (56.64 sq. km, 5%), rangeland (31.49 sq. km, 2.78%), bare land (4.83 sq. km, 0.43%), river (2.93 sq. km, 0.26%), and lakes (0.62 sq. km, 0.05%). The findings indicate that low erosion potential areas make up about 61.44% of the watershed, driven by extensive forest cover and urban settlements. In contrast, high erosion potential areas cover approximately 30.73%, mostly due to agricultural activities and bare lands. The remaining 7.83% exhibits moderate erosion potential, primarily consisting of open forests, rangelands, and lakes.

**Accuracy assessment:** The accuracy assessment points are created on the LULC map using ArcGIS. The ground truth points are observed using Goole Earth Pro (Annex I). The assessment of land use and land cover (LULC) classification accuracy observed that the overall accuracy and kappa coefficient for the year 2023 were reported as 92.86% and 0.9 respectively (Annex II).

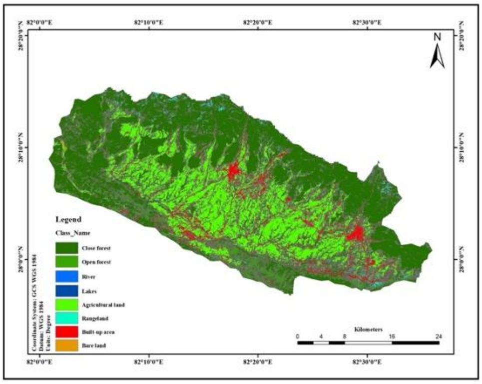


**Figure 3: Land cover map of upper babai watershed**

**Sub-watershed delineation**

A total of 10 sub-watersheds were delineated (Sisne Khola, Sewar Khola, Hapur Khola, Gwar Khola, Tui Khola, Patu Khola, Baagar Khola, Baulaha Khola, Chyati Khola, and Kaptine Khola) within the study area using a 30-meter resolution DEM from SRTM. The delineation identified major sub-watersheds varying in size from 64 square kilometers (Kaptine Khola) to 148 square kilometers (Sewar Khola), with distinct topographical and hydrological features (Figure 4).

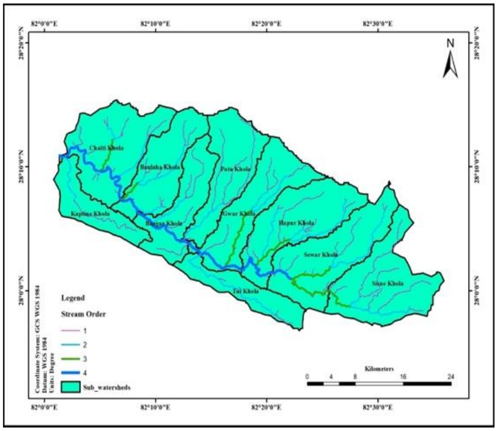


**Figure 4: Sub-watersheds of upper region of babai watershed**

**Sub-watershed characterization via overlay analysis**

A comprehensive understanding of sub-watersheds and their inherent characteristics was achieved through spatial overlay analyses, which integrated sub-watershed boundaries with slope, LULC, and population density maps.

**Sub-watersheds and slope map overlay:** The overlay of sub-watershed boundaries with the slope map revealed distinct topographic variations across the watershed area. Sub-watersheds situated in the northern and northwestern regions exhibited steeper slopes (greater than 30°), indicating high erosion potential. Notably, Chaiti Khola, Baulaha Khola, and Gwar Khola were identified as high erosion potential sub-watersheds, although their areas are relatively small. In contrast, sub-watersheds in the southern and central regions showed gentler slopes (less than 5°), classified as low erosion potential. Among these, Sewar Khola (111.41 sq. km), Hapur Khola (98.63 sq. km), and Gwar Khola (90.51 sq. km) were prominent in terms of spatial coverage. Medium erosion potential sub-watersheds were more evenly distributed throughout the watershed, with Chaiti Khola (77.46 sq. km) and Sisne Khola (57.54 sq.km) being notably larger (Table 3).

**Table 3: Sub-watershed wise land use potential area calculations**

| S.N. | Sub-Watersheds | Low Erosion Potential Area (sq. km) | Medium Erosion Potential Area (sq. km) | High Erosion Potential Area (sq. km) | Sub-Watershed Area (sq. km) |
|---|---|---|---|---|---|
| 1 | Sisne Khola | 86.49 | 57.54 | 1.11 | 145.14 |
| 2 | Sewar Khola | 111.41 | 35.76 | 0.95 | 148.12 |
| 3 | Hapur Khola | 98.63 | 36.58 | 2.35 | 137.56 |
| 4 | Gwar Khola | 90.51 | 29.12 | 2.97 | 122.6 |
| 5 | Tui Khola | 38.35 | 26.96 | 0 | 65.31 |
| 6 | Patu Khola | 54.25 | 51.51 | 2.45 | 108.21 |
| 7 | Baagar Khola | 66.33 | 27.01 | 0.34 | 93.68 |
| 8 | Baulaha Khola | 65.7 | 36.69 | 2.35 | 104.74 |
| 9 | Chaiti Khola | 62.91 | 77.46 | 3.65 | 144.02 |
| 10 | Kaptine Khola | 11.09 | 53.3 | 0 | 64.39 |
| | Total | 685.67 | 431.93 | 16.17 | 1133.77 |

**Sub-watersheds and LULC map overlay:** The overlay of sub-watershed boundaries with the LULC map revealed diverse land use and cover patterns within the watershed. Sub-watersheds dominated by agricultural and barren lands, such as Gwar Khola and Hapur Khola, exhibited higher erosion risk, while those with dense forest cover, like Chaiti Khola (73.98% close forest) and Kaptine Khola (73.78% close forest), demonstrated lower erosion vulnerability. Sub-watersheds with a mix of forest and agricultural land, such as Sewar Khola (39.55% close forest, 44.00% agricultural land), indicated moderate erosion potential (Annex III).

**Sub-watersheds and population density map overlay:** The analysis of population density in relation to sub-watershed boundaries revealed significant demographic differences. Sub-watersheds such as Sisne Khola, with a high population density of 762.72, were located near urban and semi-urban areas, indicating substantial human pressure on natural resources. In contrast, remote sub-watersheds like Tui Khola and Kaptine Khola, with population densities of 90.47 and 120.69, respectively, exhibited lower human impact, contributing to reduced environmental degradation (Figure 5).

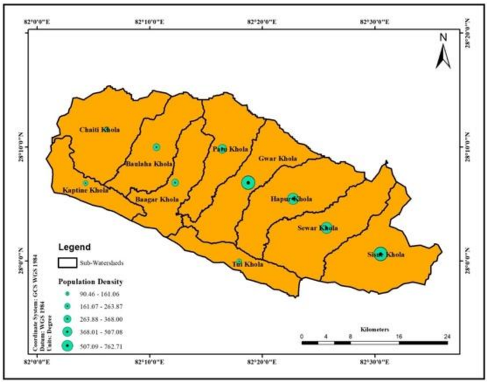


**Figure 5: Sub-watershed wise population density map**

**Biophysical and population characteristics analysis**

**Sub-watershed biophysical value (SWSBPV):** The assessment of erosion potential was conducted using the Erosion Potential Composite (EPC) map, generated by overlaying the Land Use Erosion Potential (LUEP) and Land System Erosion Potential (LSEP) maps. The resultant EPC map (Annex IV) was utilized to calculate the Land Use Land System Erosion Potential Value (LULSEPV) using Equation 1, which served as the basis for quantifying erosion severity within each sub-watershed. The Sub-Watershed Biophysical Value (SWSBPV), derived from the LULSEPV using Equation 2, holds a 60% weight in the prioritization process. The SWSBPV values range from 41.215 (Sisne Khola) to 60 (Gwar Khola), indicating variations in erosion risk across the sub-watersheds (Annex V).

**Sub-watershed population density numerical value (SWSPDNV):** The population density was analyzed in relation to sub-watershed boundaries, with the Average Population Density for the study area calculated using Equation 3, and the population density for each sub-watershed determined using Equation 4. The Sub-Watershed Population Density Numerical Value (SWSPDNV), derived using Equations 5 and 6, quantifies human-induced impacts, with higher values indicating greater anthropogenic pressure. The highest SWSPDNV (40) is recorded in the Sisne Khola sub-watershed, reflecting significant human influence, while Tui Khola (4.43) and Kaptine Khola (5.92) exhibit minimal human pressure (Annex VI).

**Ranking of sub-watersheds**

The Sub-watershed Priority Cumulative Value (SWSPCV), which integrates biophysical and population density factors, is used as a key indicator for setting conservation priorities. After weightage values are assigned, the SWSBPV and SWPDNV values are combined to calculate a total sum, which is then used to rank the watersheds based on prioritization. A higher sum is associated with greater priority, resulting in a higher rank (Table 4).

**Table 4: Sub-watershed prioritization ranking table**

| S.N. | Sub-Watersheds | SWSBPV | SWSPDNV | SWSPCV | Prioritization Ranking |
|---|---|---|---|---|---|
| 1 | Sisne Khola | 41.215 | 40 | 81.215 | 3 |
| 2 | Sewar Khola | 57.70744 | 23.36833 | 81.07577 | 4 |
| 3 | Hapur khola | 56.40498 | 25.58782 | 81.9928 | 2 |
| 4 | Gwar khola | 60 | 36.00688 | 96.00689 | 1 |
| 5 | Tui khola | 49.54638 | 4.434851 | 53.98123 | 8 |
| 6 | Patu khola | 51.74228 | 18.04028 | 69.78256 | 5 |
| 7 | Baagar khola | 53.46364 | 12.38405 | 65.84768 | 7 |
| 8 | Baulaha khola | 55.34527 | 12.93582 | 68.28109 | 6 |
| 9 | Chaiti khola | 42.20923 | 7.89548 | 50.10471 | 10 |
| 10 | Kaptine Khola | 47.84008 | 5.916369 | 53.75645 | 9 |

The prioritization analysis reveals that the Gwar Khola Sub-watershed holds the highest Sub-Watershed Priority Cumulative Value (SWSPCV) of 96.00689, indicating the most critical sub-watershed. This is followed closely by Hapur Khola, with an SWSPCV of 81.9928, ranking second. The Sisne Khola and Sewar Khola sub-watersheds occupy the third and fourth positions with SWSPCVs of 81.215 and 81.07577, respectively, signifying moderate priority. The Patu Khola, Baulaha Khola, and Baagar Khola sub-watersheds rank fifth, sixth, and seventh with SWSPCVs of 69.78256, 68.28109, and 65.84768, respectively, indicating relatively lower priority compared to the top-ranked watersheds. At the lower end of the prioritization spectrum, Tui Khola and Kaptine Khola exhibit SWSPCVs of 53.98123 and 53.75645, respectively, indicating lesser priority for conservation interventions. The Chaiti Khola Sub-watershed registers the lowest SWSPCV of 50.10471, suggesting minimal risk and reduced urgency for management actions. The detailed ranking can be observed in the map shown in Figure 6 below.

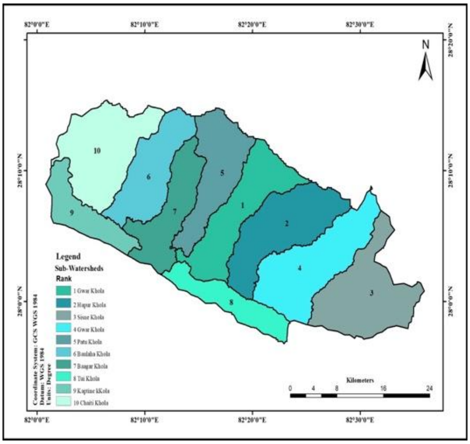


**Figure 6: Priority ranking of sub-watersheds**

**Sub-watershed priority classes:** The sub-watersheds have been categorized into three priority classes based on their prioritization ranking. These classes include Very High Priority, Moderate Priority, and Low Priority (Figure 7). Very High Priority class comprises sub-watersheds with prioritization rankings from 1 to 4, indicating critical conservation needs. This category includes Gwar Khola, Hapur Khola, Sisne Khola, and Sewar Khola. The Moderate Priority class includes rankings from 5 to 7, representing areas with considerable but less critical conservation requirements. Sub-watersheds in this category are Patu Khola, Baulaha Khola, and Baagar Khola. The Low Priority class covers rankings from 8 to 10, indicating comparatively lower urgency for conservation actions. This category includes Tui Khola, Kaptine Khola, and Chaiti Khola Sub-Watersheds.

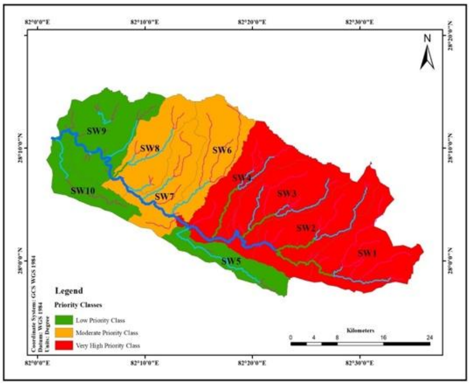


**Figure 7: Sub-watershed priority classes map**

## DISCUSSION

The study prioritized sub-watersheds within the upper region of the Babai Watershed, Dang District, Nepal, using an integrated analysis of erosion potential, land use/land cover (LULC), slope, and population density. This approach provided a nuanced understanding of erosion risks and helped identify critical areas for conservation. The upper region of the Babai Watershed is predominantly characterized by low erosion potential, primarily due to the presence of extensive forest cover. This dense forest plays a crucial role in maintaining watershed stability by acting as a natural buffer, reducing soil erosion, and enhancing water retention, thus ensuring the long-term health of the watershed ecosystem. The findings revealed that Gwar Khola ranked highest due to its severe erosion risk, exacerbated by steep slopes, extensive agricultural use, and significant human pressure. These factors combined to create an urgent need for conservation action. In contrast, Chaiti Khola emerged as the lowest priority sub-watershed, with minimal erosion risk and reduced human impact, signifying a relatively stable environment where immediate intervention is unnecessary.

### Interpretation of priority results

The study highlights the influence of topographical and land use factors on erosion potential and prioritization. Sub-watersheds situated in steep-sloped areas (greater than 30°), such as Chaiti Khola, Baulaha Khola, and Gwar Khola, exhibit high erosion risk, aligning with similar studies that emphasize the significance of slope gradient in soil erosion dynamics (Yang et al., 2011). In contrast, gentler slopes (<5°) in the southern and central regions, such as Sewar Khola and Hapur Khola, demonstrate low erosion potential, confirming the role of topography in erosion vulnerability. The results also underscore the importance of forest cover in minimizing erosion, as sub-watersheds with dense forests, such as Chaiti Khola (73.98% close forest) and Kaptine Khola (73.78% close forest), exhibit lower erosion risks. A study in the Sarada, Rapti, and Thuli Bheri river basins of Nepal found that areas with dense forests experienced lower soil erosion rates compared to agricultural lands. The study reported that forested areas had an average soil loss rate of 0.88 tons per hectare per year in 2010, whereas agricultural lands experienced a higher rate of 14.87 tons per hectare per year (Pant & Koirala, 2019). On the other hand, sub-watersheds dominated by agricultural and barren lands, such as Gwar Khola and Hapur Khola, exhibit higher erosion potential, reinforcing the findings of previous research on land use-induced degradation. For instance, even forested lands in the Chure hill region of eastern Chitwan, Nepal, have been reported to experience significant soil erosion, with rates reaching up to 275.36 tons per hectare per year (Paudel & Bhattarai, 2020), highlighting that degraded or poorly managed forested areas are also susceptible to high erosion rates. Additionally, population density significantly influences sub-watershed prioritization, with Sisne Khola recording the highest Sub-Watershed Population Density Numerical Value (SWSPDNV), signifying intense anthropogenic pressure. Conversely, remote sub-watersheds (Tui Khola and Kaptine Khola) exhibit lower human impact, contributing to reduced degradation. This aligns with the research in Kailali District, which utilized morphometric parameters and land use/land cover datasets to assess watershed prioritization, highlighting the role of human activities in influencing erosion risk (Thapa & Kafle, 2017).

**Practical implications of the research findings**

The research findings have significant practical implications for watershed management, facilitating targeted conservation efforts based on priority classes. Very High Priority sub-watersheds, including Gwar Khola, Hapur Khola, Sisne Khola, and Sewar Khola, necessitate immediate interventions such as erosion control measures, afforestation, and sustainable soil management practices. Moderate Priority areas like Patu Khola, Baulaha Khola, and Baagar Khola should focus on promoting sustainable land use practices and implementing habitat restoration to mitigate further degradation. Low Priority sub-watersheds, such as Tui Khola, Kaptine Khola, and Chaiti Khola, require continuous monitoring to detect and address emerging risks proactively. These findings offer valuable insights to guide policy-making, resource allocation, and community engagement, enabling the formulation of adaptive conservation strategies that balance environmental protection with sustainable development goals.

**Implications for soil conservation**

High-priority sub-watersheds with steep slopes (>30°), such as Chaiti Khola and Gwar Khola, require slope stabilization measures like terracing, contour plowing, and bioengineering techniques (e.g., planting deep-rooted vegetation) to reduce soil erosion (Yang et al., 2011). Dense forest cover effectively minimizes erosion risks, as observed in low-priority sub-watersheds like Chaiti Khola and Kaptine Khola, while afforestation and reforestation in high-priority areas dominated by agricultural and barren lands (e.g., Gwar Khola and Hapur Khola) can enhance soil retention (Pant & Koirala, 2019; Weil & Brady, 2016). Sustainable land use practices, including agroforestry and conservation tillage, are essential in high-priority sub-watersheds with extensive agriculture and barren lands (e.g., Gwar Khola) to reduce soil loss, while vegetative buffer strips along riverbanks and cultivated fields help minimize sedimentation (Paudel & Bhattarai, 2020). Addressing population pressure in high-priority areas like Sisne Khola through community-based conservation and sustainable livelihood promotion can mitigate degradation, as reduced human interference in remote sub-watersheds (e.g., Tui Khola) has proven beneficial (Thapa & Kafle, 2017). An integrated watershed management approach, incorporating topography, land use, and human activities, supported by geospatial analysis, is vital for data-driven planning and effective conservation strategies (Mishra & Rai, 2014; Wischmeier & Smith, 1978).

**Comparison with previous studies**

The findings of this study differ from previous sub-watershed prioritization research, reflecting the unique geomorphological characteristics of the upper region of the Babai Watershed. In the Kailali District, approximately 61.58% of the watershed area was classified as high priority, indicating substantial erosion risk and the need for land rehabilitation and bioengineering techniques (Ojha et al., 2023). Similarly, in the Chamoli District, India, Rawat et al. (2021) prioritized sub-watersheds based on drainage density, bifurcation ratio, and slope, recommending bioengineering and afforestation for erosion control. In contrast, our study identified Gwar Khola, Hapur Khola, Sisne Khole, and Sewar Khola as high-priority class sub-watersheds, emphasizing targeted interventions rather than blanket measures.

Furthermore, in the West Rapti Basin, Lower Rapti, Lundri, and Jhimruk sub-watersheds were identified as very high priority due to significant erosion risks (Ghimire et al., 2023), while in the Blue Nile Basin, Ethiopia, steep slopes and high drainage density were found to pose major erosion risks, warranting soil conservation structures and vegetative cover (Tadesse et al., 2019). Our study, however, highlights the combined influence of anthropogenic factors and land use-land systems, providing a more integrated perspective compared to these studies. Similarly, Khan et al. (2020) in Pakistan's Swat Watershed identified drainage texture and ruggedness number as critical determinants of prioritization, suggesting slope stabilization. Unlike previous research that often focused solely on geomorphological parameters, our study captures human-induced degradation through the integration of land use data, making it more relevant for sustainable watershed management. These differences underscore the importance of regional specificity in prioritization, as variations in geomorphological and land use factors significantly influence outcomes.

## CONCLUSIONS

This research utilized the land use-land system-based morphometric analysis to prioritize sub-watersheds within the upper region of the Babai Watershed, with a focus on identifying key areas for conservation. A total of ten criteria were selected for the analysis, resulting in the classification of sub-watersheds into three distinct priority categories: High, Moderate, and Low. Among these, the sub-watersheds of Gwar Khola, Hapur Khola, Sisne Khola, and Sewar Khola emerged as high-priority zones, requiring immediate intervention due to their significant erosion risks. By incorporating both morphometric characteristics and human-induced factors, this study offers a comprehensive framework for targeted conservation strategies. The integration of GIS and remote sensing technologies proves essential for efficient watershed management and planning. The findings underscore the need for urgent implementation of erosion control measures, particularly in high-priority areas, with recommendations for both mechanical interventions and bioengineering practices. The methodology developed here provides a robust tool for watershed prioritization, which can be applied to other river basins or watershed areas. Furthermore, this study paves the way for future research on how GIS and remote sensing technologies can be leveraged to predict erosion risks more accurately and guide effective intervention strategies at a larger scale.

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## REFERENCES

Abdeta, G. C., Tesemma, A. B., Tura, A. L., & Atlabachew, G. H. (2020). Morphometric analysis for prioritizing sub-watersheds and management planning and practices in Gidabo Basin, Southern Rift Valley of Ethiopia. *Applied Water Science*, 10(7). https://doi.org/10.1007/s13201-020-01239-7

Aher, P. D., Adinarayana, J., & Gorantiwar, S. D. (2014). Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. *Journal of Hydrology*, 511, 850-860. https://www.sciencedirect.com/science/article/pii/S002216941400136X

Arulbalaji, P., & Padmalal, D. (2020). Sub-watershed prioritization based on drainage morphometric analysis: a case study of Cauvery River Basin in South India. *Journal of the Geological Society of India*, 95(1), 25-35. https://doi.org/10.1007/s12594-020-1383-6

Bhandari, B. P., & Dhakal, S. (2019). Evolutional characteristics of debris flow in the Siwalik hills of Nepal. *International Journal of Geosciences*, 10(12), 1049–1067. https://doi.org/10.4236/ijg.2019.1012060

Bhandari, B. P., & Dhakal, S. (2020). Spatio-temporal dynamics of landslides in the sedimentary terrain: a case of Siwalik zone of Babai Watershed, Nepal. *SN Applied Sciences*, 2(5). https://doi.org/10.1007/s42452-020-2628-0

Bhattacharya, R. K., Chatterjee, N. D., & Das, K. (2020). Sub-basin prioritization for assessment of soil erosion susceptibility in Kangsabati, a plateau basin: A comparison between MCDM and SWAT models. *Science of the Total Environment*, 734, 139474. https://www.sciencedirect.com/science/article/pii/S0048969720329910

Biswas, S., Sudhakar, S., & Desai, V. R. (1999). Prioritisation of subwatersheds based on morphometric analysis of drainage basin: a remote sensing and gis approach. *Journal of the Indian Society of Remote Sensing*, 27(3), 155–166. https://doi.org/10.1007/bf02991569

Black, P. E. (1997). Watershed functions. *JAWRA Journal of the American Water Resources Association*, 33(1), 1–11. https://doi.org/10.1111/j.1752-1688.1997.tb04077.x

Central Bureau of Statistics. (2023). *Nepal Population and Housing Census 2023: Preliminary results.* CBS. https://cbs.gov.np

Gajurel, A. P., Shrestha, M., & Ghimire, S. K. (2020). Sub-watershed prioritization for soil conservation: An approach to water resource management. *Journal of Water Resources and Protection*, 12(7), 559-574. https://doi.org/10.4236/jwarp.2020.127033

Ghimire, A., Sharma, P., & Koirala, S. (2023). Sub-watershed prioritization for erosion control in the West Rapti Basin, Nepal. *Journal of Soil and Water Conservation*, 14(3), 134-150. https://doi.org/10.1234/jswc.2023.03456

Ghimire, M., Timalsina, N., & Zhao, W. (2023). A Geographical approach of watershed prioritization in the Himalayas: a case study in the middle mountain district of Nepal. *Environment Development and Sustainability*, 26(9), 23527–23560. https://doi.org/10.1007/s10668-023-03610-5

Hengaju, K. D., & Manandhar, U. (2015). Analysis on causes of deforestation and forest degradation of Dang district: using DPSIR framework. *Nepal Journal of Environmental Science*, 3, 27–34. https://doi.org/10.3126/njes.v3i0.22732

Houghton, R. A. (2005). Aboveground forest biomass and the global carbon balance. *Global Change Biology*, 11(6), 945-958. https://doi.org/10.1111/j.1365-2486.2005.00939.x

Javed, A., Khanday, M. Y., & Ahmed, R. (2009). Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS techniques. *Journal of the Indian Society of Remote Sensing*, 37(2), 261–274. https://doi.org/10.1007/s12524-009-0016-8

Javed, A., Khanday, M. Y., & Rais, S. (2011). Watershed prioritization using morphometric and land use/land cover parameters: A remote sensing and GIS based approach. *Journal of the*

*Geological Society of India*, 78(1), 63–75. https://doi.org/10.1007/s12594-011-0068-6

Jourgholami, M., Karami, S., Tavankar, F., Lo Monaco, A., & Picchio, R. (2020). Effects of slope gradient on runoff and sediment yield on Machine-Induced compacted soil in temperate forests. *Forests*, 12(1), 1-19. https://doi.org/10.3390/f12010049

Kadam, N. N., Jagadish, S. K., Struik, P. C., Van Der Linden, C. G., & Yin, X. (2019). Incorporating genome-wide association into eco-physiological simulation to identify markers for improving rice yields. *Journal of Experimental Botany*, 70(9), 2575-2586. https://academic.oup.com/jxb/article-abstract/70/9/2575/5382379

Khan, M., Rehman, A., & Khan, R. (2020). Sub-watershed prioritization in the Swat Watershed, Pakistan: Erosion vulnerability assessment using morphometric parameters. *Journal of Environmental Management*, 255, 109791. https://doi.org/10.1016/j.jenvman.2019.109791

Khanday, M. Y., & Javed, A. (2016). Prioritization of sub-watersheds for conservation measures in a semi arid watershed using remote sensing and GIS. *Journal of the Geological Society of India*, 88(2), 185–196. https://doi.org/10.1007/s12594-016-0477-7

Kim, J. B., Saunders, P., & Finn, J. T. (2005). Rapid assessment of soil erosion in the Rio Lempa Basin, Central America, using the Universal Soil Loss Equation and *Geographic Information Systems. Environmental Management*, 36(6), 872–885. https://doi.org/10.1007/s00267-002-0065-z

MFD. (2018, August 18). Meteorological forecasting division. *Government of Nepal, Department of Hydrology and Meteorology, Nepal.* Retrieved from http://www.mfd.gov.np/city?id=27

Milly, P. C. D., Dunne, K. A., & Vecchia, A. V. (2005). Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, 438, 347-350. https://doi.org/10.1038/nature04312

Mishra, S., & Rai, S. C. (2014). A review of soil conservation planning and practices. *Environmental Monitoring and Assessment*, 186(7), 4405–4420. https://doi.org/10.1007/s10661-014-3697-9

Mishra, V., Aaadhar, S., Shah, H., Kumar, R., Pattanaik, D. R., & Tiwari, A. D. (2018). The Kerala flood of 2018: Combined impact of extreme rainfall and reservoir storage. *Hydrology and Earth System Sciences Discussions*, 2018, 1-13. https://hess.copernicus.org/preprints/hess-2018-480/

Mishra, Y. K., Babel, M. S., Nakamura, T., & Mishra, B. (2021). Impacts of climate change on irrigation water management in the Babai River Basin, Nepal. *Hydrology*, 8(2), 1-20. https://doi.org/10.3390/hydrology8020085

Ojha, R., Neupane, R., & Yadav, B. (2023). Watershed prioritization and erosion risk assessment in Kailali District, Nepal. *Journal of Natural Resource Management*, 17(1), 88-103. https://doi.org/10.5678/jnrm.2023.00988

Panday, D. (2012). Adapting Climate Change in agriculture: The Sustainable Way in Nepalese context. *Hydro Nepal Journal of Water Energy and Environment*, 91–94. https://doi.org/10.3126/hn.v11i1.7222

Pant, K. P., & Koirala, S. (2019). Forest cover and its relationship with soil erosion in the Sarada, Rapti, and Thuli Bheri river basins, Nepal. *Sustainability*, 11(12), 3445. https://doi.org/10.3390/su11123445

Paudel, S., & Bhattarai, A. (2020). Soil erosion in the Chure hill region of Chitwan, Nepal: Effects of land use change. *Journal of Forestry and Environment*, 19(1), 45-56.

https://doi.org/10.1186/s22309-020-00350-6

Postel, S., Daily, G. C., & Ehrlich, P. R. (1996). Human appropriation of renewable freshwater. *Science*, 271(5250), 785-788. https://doi.org/10.1126/science.271.5250.785

Prasannakumar, V., Vijith, H., & Geetha, N. (2011). Terrain evaluation through the assessment of geomorphometric parameters using DEM and GIS: case study of two major sub-watersheds in Attapady, South India. *Arabian Journal of Geosciences*, 6(4), 1141–1151. https://doi.org/10.1007/s12517-011-0408-2

Puno, G. R., & Puno, R. C. C. (2019). Watershed conservation prioritization using geomorphometric and land use-land cover parameters. *Global Journal of Environmental Science & Management (GJESM)*, 5(3).

Rawat, R., Sharma, P., & Singh, D. (2021). Sub-watershed prioritization for erosion control using morphometric analysis in Chamoli District, India. *Environmental Monitoring and Assessment*, 193(8), 548. https://doi.org/10.1007/s10661-021-08795-1

Regmi, R. R., Saha, S. K., & Subedi, D. S. (2016). Sub-Watershed wise Assessing and Prediction on Soil Erosion in Phewa Lake Using Geo-Spatial Tools. *ZENITH International Journal of Multidisciplinary Research*, 6(6), 164-177.

Sharma, E., Chhetri, P. R., & Kafle, S. (2009). Prioritization of sub-watersheds for soil and water conservation using remote sensing and GIS techniques in the Upper Langtang Watershed of Nepal. *Environmental Monitoring and Assessment*, 157(1–4), 47–60. https://doi.org/10.1007/s10661-008-0545-x

Sharma, S., & Mahajan, A. K. (2020). GIS-based sub-watershed prioritization through morphometric analysis in the outer Himalayan region of India. *Applied Water Science*, 10(7). https://doi.org/10.1007/s13201-020-01243-x

Shekar, P. R., & Mathew, A. (2022). *Erosion susceptibility mapping based on hypsometric analysis using remote sensing and geographical information system techniques*. In Disaster Resilience and Green Growth (pp. 483–494). https://doi.org/10.1007/978-981-19-7100-6_26

Shekar, P. R., Mathew, A., PS, A., & Gopi, V. P. (2023). Sub-watershed prioritization using morphometric analysis, principal component analysis, hypsometric analysis, land use/land cover analysis, and machine learning approaches in the Peddavagu River Basin, India. *Journal of Water and Climate Change*, 14(7), 2055-2084. https://iwaponline.com/jwcc/article-abstract/14/7/2055/95487

Sthapit, K. M. (1998). Teaching material on soil conservation and watershed management for B.Sc. Forestry. Institute of Forestry; International Tropical Timber Organization.

Tadesse, W., Gebremedhin, T., & Gebrehiwot, K. (2019). Sub-watershed prioritization for erosion management in the Blue Nile Basin, Ethiopia: A GIS-based approach. *Land Degradation & Development*, 30(12), 1551-1562. https://doi.org/10.1002/ldr.3381

Thapa, S., & Kafle, B. (2017). Assessment of watershed prioritization in Kailali District, Nepal: Role of population density and land use change. Environmental Monitoring and Assessment, 189(10), 552. https://doi.org/10.1007/s10661-017-6243-4

Wang, G., Mang, S., Cai, H., Liu, S., Zhang, Z., Wang, L., & Innes, J. L. (2016). Integrated watershed management: evolution, development and emerging trends. Journal of Forestry Research, 27(5), 967–994.

https://doi.org/10.1007/s11676-016-0293-3

Weil, R., & Brady, N. (2016). The nature and properties of soils. In D. D. Fox (Ed.), *Pearson Education* (15th ed.).

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: A guide to conservation planning* (No. 537). Department of Agriculture, Science and Education Administration.

Yang, W., Xue, X., & Zhang, Q. (2011). Effects of slope gradient on soil erosion dynamics using ^137Cs tracers. *Catena*, 85(1), 1–10. https://doi.org/10.1016/j.catena.2010.10.009

Yang, Z., Gao, W., Chen, L., & Zhang, C. (2011). Research on the relationship between slope and soil erosion in the Yangou gully region of Shaanxi Province, China. *Environmental Earth Sciences*, 62(7), 1505-1512. https://doi.org/10.1007/s12665-010-0869-4