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Panzara River Watershed Prioritization Based on Geomorphometric and LULC Change Analysis using Geo-Spatial Techniques

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Abstract:- Human activities can significantly influence the quality of water flowing from a watershed, either positively or negatively. As water moves through the system, these impacts accumulate, with all land-based activities having the potential to affect the water quality and quantity experienced by downstream stakeholders. Similarly, the actions of upstream landowners impact the water that flows across others' properties. Geospatial techniques like remote sensing and geographic information systems (GIS) are invaluable tools for analysing drainage patterns within a watershed and the associated changes in land use and cover. This study focuses on the Panzara river basin, a principal tributary of the larger Tapi river basin, situated in central India between the westward-flowing Godavari and Narmada river systems, which both ultimately discharge into the Arabian Sea. The study area spans latitudes from 20°42'0" N to 21°18'0" N and longitudes from 74°06'0" E to 75°00'0" E, covering a geographical area of 2,986.05 square kilometers with a perimeter of 570.51 kilometers. The watershed delineation was carried out using Shuttle Radar Terrain Mapper (SRTM) data with a 30-meter resolution. For land use and land cover (LULC) analysis, Landsat 5 TM C2L1 and Landsat 8 OLI/TIRS C2L1 datasets, both with 30-meter resolution, were utilized. The present study conducts a morphometric analysis and assesses LULC changes within the Panzara river basin between 2000 and 2021. Morphometric parameters such as linear parameters [Drainage density (Dd), Stream frequency (Fs), Mean bifurcation ratio (Rbm), Drainage texture ratio (Dt), Length of overland flow (Lo)] and areal parameters [Elongation ratio (Re), Circulatory ratio (Cr), Form factor (Rf), Compactness coefficient (Cc)] were used to prioritize sub-watersheds. Furthermore, the study classifies the observed LULC changes between satellite imagery datasets from 2000 and 2021, quantifying the percentage changes in the respective LULC classes across the sub-watersheds over the two decades. The overall accuracy of the LULC classification was 81.82% for 2000 and 88.88% for 2021, with Kappa coefficients of 0.772 and 0.85, respectively. In terms of prioritizing sub-watersheds, common sub-watersheds such as SW-1, SW-10, and SW-15 were classified under moderate priority, while SW-5, SW-8, and SW-14 were classified under the lowest priority. The results of this study, particularly the prioritization of sub-watersheds, can be instrumental for hydraulic engineers in planning and managing water resources in the Panzara river basin.

Keywords:- *Watershed, Morphometry, LULC Change, GIS, Priority****.***

I. INTRODUCTION

Human activities within a watershed can significantly influence the quality of water flowing through the system, either positively or negatively. Every land-based action within a watershed impacts the water quality experienced by downstream users, just as the decisions of upstream landowners affect water resources accessed by those lower in the watershed. A watershed is a natural hydrological unit that channels surface runoff from rainfall through streams, rivers, lakes, and eventually into oceans (Chopra, Dhiman, and Sharma 2005). This makes watersheds ideal for the management and sustainable development of natural resources. The relationship between land use, soil, and water defines the principles of watershed management.

The structure of a drainage basin and its stream channel arrangement can be understood through various features (Horton 1945). These include stream length, stream order, bifurcation ratio, stream frequency, form factor, circulatory ratio, elongation ratio, texture ratio, compactness coefficient, relief ratio, overland flow, and drainage density (Nag and Chakraborty 2003). Morphometric analysis provides a quantitative description of the drainage system, encompassing both linear and areal parameters. The development of quantitative analysis in hydrology has evolved from earlier qualitative research and contributions, notably the modifications and extensions of Horton's laws by geomorphologists like Strahler (1952, 1957) and Melton (1957).

Geospatial technologies, such as remote sensing and geographic information systems (GIS), offer powerful analytical capabilities for examining the drainage characteristics of a watershed. Morphometric analysis can be instrumental in identifying appropriate water conservation

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infrastructure, such as check dams, trenches, farm ponds, and spillways, within a watershed.

Land use and land cover (LULC) changes are often directly or indirectly influenced by population growth. For instance, population growth in a specific area typically leads to an increase in built-up areas and a decrease in other land classes like agriculture, barren land, and forest. LULC data are vital for selecting, planning, and sustainably managing land resources, as well as understanding changes in hydrological processes to meet increasing demands for basic human needs. LULC analysis is also used to assess risk, prioritize sub-watersheds for development planning and conservation strategies, and protect the environment from degradation. Understanding changes in land cover and their ecological impacts is crucial for natural resource management, and analyzing the external factors driving these changes is essential for forecasting future alterations.

The study of LULC changes through spatio-temporal analysis provides a foundation for the sustainable management of natural resources, reflecting the state of the watershed (Twisa and Buchroithner 2019). The advent of remote sensing and GIS techniques has significantly improved the accuracy and efficiency of land use/cover mapping, allowing for more informed decisions regarding the allocation of agricultural, urban, and industrial areas. Remotely sensed data enables the study of land cover changes with greater speed, lower cost, and better accuracy within a GIS environment, which offers a robust platform for data analysis, manipulation, and retrieval (Rawat and Kumar 2015).

The present study focuses on prioritizing sub-watersheds through the analysis of Digital Elevation Models (DEMs) and LULC data, aiming to enhance the management and planning of watersheds. By comparing morphometric analysis with LULC analysis, the study seeks to prioritize sub-watersheds effectively. The findings of this study are expected to provide valuable insights for managing and planning watersheds in a sustainable manner, ensuring the long-term viability of these critical natural resources.

II. STUDY AREA

The study area, Panzara Basin, is located in the Khandesh region of Dhule District, Maharashtra. The Panzara River, the primary tributary of the Tapi River basin, is situated in central India between the Godavari and Narmada rivers, both of which flow westward before emptying into the Arabian Sea. The Panzara River originates a few kilometers from the small town of Pimpalner. The basin extends between latitudes 20°42'0" N to 21°18'0" N and longitudes 74°06'0" E to 75°00'0" E, covering a geographical area of 2,986.05 square kilometers with a perimeter of 570.51 kilometers. The total length of the Panzara River is 14.57 kilometers.

The watershed spans five districts: Dhule, Jalgaon, Nashik, Nandurbar in Maharashtra, and The Dangs in Gujarat. However, the central portion of the watershed primarily lies within Dhule District, Maharashtra. A small reservoir, the Latipada Dam, is constructed near the origin of the Panzara River. The study area experiences a hot summer, with general dryness prevailing throughout the year except during the monsoon season from June to September, according to climatological data. The study area map is depicted in Figure 1.

III. METHODOLOGY

This study is organized into two main methods of analysis: morphometric analysis and land use/land cover (LULC) analysis.

A. Morphometric Analysis

The Panzara watershed and its associated sub-watershed drainage networks were delineated using a Shuttle Radar Terrain Mapper (SRTM) Digital Elevation Model (DEM) with a 30-meter spatial resolution, obtained from the United States Geological Survey (USGS) Earth Explorer portal. The DEM was processed using Arc SWAT and Arc Hydrology tools within the Spatial Analyst module of ArcGIS software to create representations of the watershed and drainage network. SRTM DEM-based hydrological evaluation at the watershed scale is considered more precise and practical than other methods (Singh, Gupta, and Singh 2014).

The first critical step involved delineating the boundaries of the basin and sub-basins, as well as extracting the drainage network. Each drainage segment was numerically ordered using ArcGIS 10.5 software. Key linear and areal aspects of drainage morphometry were then calculated using appropriate formulas, and the results were analyzed in the context of the Panzara River basin.

The watershed was divided into sixteen sub-basins, as shown in Figure 3. Based on an assessment of geomorphological characteristics, a priority ranking was established for the sixteen sub-basins according to eight morphometric parameters: bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio, and basin shape. These sub-basins were prioritized by evaluating a 'Compound Parameter,' with each parameter given equal importance. The average value of the compound parameter was calculated for each sub-watershed, with the sub-basin having the lowest compound parameter value assigned the highest priority and recommended for urgent conservation measures to mitigate erosion.

Soil loss in the watershed is either directly or inversely proportional to these parameters. For instance, soil loss is directly proportional to bifurcation ratio, drainage density, stream frequency, texture ratio, relief ratio, and length of overland flow, while it is inversely proportional to circulatory ratio, form factor, elongation ratio, and compactness coefficient (Biswas, Sudhakar, and Desai 1999; Nooka Ratnam et al. 2005; Javed, Khanday, and Ahmed 2009). The sub-watersheds were prioritized to

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preserve the topsoil, which is more fertile and crucial for food production (Prabhakar et al., 2019).

B. Land Use/Land Cover (LULC) Map Analysis

In remote sensing studies, representative ground truth data is essential for associating reflectance properties with objects and for training classifiers to facilitate accurate automatic classification (Muzein 2006). This study utilized two datasets: 1) Landsat 5 TM C2L1 data, which includes six spectral bands with 30m resolution and one thermal band with 120m resolution, from March 2000, and 2) Landsat 8 OLI/TIRS C2L1 data, which includes nine spectral bands with 30m resolution and two thermal bands with 100m resolution, from March 2021.

Supervised classification and change detection analysis techniques were used to generate and verify land cover information for the study region. A thorough literature review was conducted to select the most appropriate classification method. Popular supervised classification techniques, such as the Maximum Likelihood Classifier, have been widely used in LULC classification studies (Rao and Narendra 2006; Andreoli et al. 2007). Accordingly, this study employed the Maximum Likelihood Classifier in ArcMap 10.5 software for land use/land cover classification.

The watershed and sub-watershed of the Panzara River were classified into five land feature classes: agricultural land, barren land, forest, waterbody, and settlement. Accuracy assessment is a crucial aspect of evaluating the reliability of a map, as no image classification is considered complete until its accuracy is assessed. LULC changes are vital for studying regional, local, and global environmental changes (Gupta and Munshi 1985; Mas 1999).

IV. RESULT AND DISCUSSION

The results of this study are discussed below, focusing on the morphometric analysis of the Panzara River basin. The morphometric parameters are broadly categorized into linear and areal aspects of the basin, with the drainage characteristics being analyzed in the following sections.

A. Linear Aspects

- *Stream Order (Nu)*

Stream order is a fundamental step in drainage basin analysis, involving the hierarchical ranking of streams based on their size and extent. In this study, stream hierarchy was determined using the method proposed by Strahler (1964). The stream network of the study area includes channels of first, second, third, fourth, and fifth orders. When two streams of the same order converge, they form a higher-order stream. In watershed geomorphology, stream orders increase as one moves downstream. The first-order streams account for the highest percentage (72.79%) of the total stream orders, while the fifth-order streams represent the smallest percentage (0.85%). Figure 2 illustrates the stream order hierarchy of the Panzara River basin, and Table 2 provides a sub-watershed-wise distribution of stream order and the total number of stream segments.

- *Stream Length (Lu)*

According to Horton’s second law (1945), the characteristics of stream length in sub-basins support the "laws of stream length," which suggest that the average length of streams in each order in a drainage basin tends to follow a geometric ratio (Horton 1945). The total stream length (Lu) across all sub-watersheds was measured using GIS software. The data shows that stream length decreases as stream order increases, as detailed in Table 3. The stream length ratio, defined as the ratio of the mean stream length (Lu) of a particular order (So) to the mean length of the next lower order (Lu-1), can reflect factors such as streams flowing from high altitudes, lithological variations, and slope gradients (Vittala, Govindaiah, and Gowda 2004; S. Singh and Singh 1997). The total stream network length extracted from SRTM DEM data is 3,016 km, with the first order accounting for 1,458 km (48.34%), followed by the second order at 740 km (24.54%), third order at 407 km (13.49%), fourth order at 295 km (9.78%), and fifth order at 116.02 km (3.85%). The validation of Horton’s laws for 'Nu' and 'Lu' supports the concept of geometrical similarity in basins with increasing stream order (Strahler 1957). The mean stream length ratio for the basin ranges from 0.33 to 1.28, as shown in Table 4.

- *Bifurcation Ratio (Rb)*

The bifurcation ratio (Rb) typically shows limited variation across different regions, unless geological factors significantly influence the drainage network. The bifurcation ratio reflects both the geological and tectonic characteristics of a watershed (Gajbhiye, Mishra, and Pandey 2014). It is calculated as the ratio of the number of streams of a given order to the number of streams in the next higher order. A lower Rb value indicates a relatively undisturbed watershed with minimal distortion in the drainage pattern (Nag 1998). Conversely, a high bifurcation ratio suggests increased overland flow and reduced groundwater recharge within the sub-watershed. According to Strahler (1964), the typical Rb value ranges from 3.0 to 5.0 in watersheds where the geological structure does not disrupt the drainage pattern. In this study, the bifurcation ratio for the sixteen sub-watersheds exceeds 2, indicating a rolling drainage surface. Higher bifurcation ratios suggest increased soil erosion and reduced groundwater recharge in the respective sub-watersheds. The mean bifurcation ratio across the sub-watersheds ranges from 2.83 to 4.91, as detailed in Table 5.

B. Areal Aspects

- *Drainage Density (Dd)*

Drainage density (Dd) is defined as the total length of streams per unit area within a drainage basin (Horton, 1945). This parameter is crucial in understanding the basin’s hydrological behavior, as it reflects the interplay between climate, lithology, and structural characteristics. Basins with low drainage density generally have porous surface materials and good vegetation cover, whereas high drainage density indicates low permeability and significant erosion. In this study, the drainage density of the Panzara basin ranges from 0.79 to 1.35, as shown in Table 6.

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➢ *Stream Frequency (Fs)*

Stream frequency (Fs) refers to the number of stream segments per unit area (Horton, 1945). This parameter is an indicator of the basin's topography, and it is directly proportional to drainage density—meaning that an increase in stream segments leads to higher drainage density. The stream frequency in this study varies from 0.35 to 0.57. Sub-watershed 8 has the lowest stream frequency (0.35), indicating minimal erosion, while sub-watershed 6 shows the highest stream frequency (0.57), suggesting higher runoff and greater soil erosion.

➢ *Drainage Texture Ratio (Rt)*

The drainage texture ratio (Rt) is calculated as the total number of stream segments across all orders divided by the watershed perimeter. According to Horton, the infiltration capacity is a key factor influencing the drainage texture ratio, which also incorporates drainage density and stream frequency. The classification system categorizes drainage texture ratios as follows: values less than 2 indicate very coarse texture, 2 to 4 is coarse, 4 to 6 is moderate, 6 to 8 is fine, and greater than 8 is very fine. The sub-watersheds in this study exhibit drainage texture ratios ranging from 0.31 to 1.24, indicating a very coarse drainage texture and minimal slope variation in the relatively flat basin.

➢ *Form Factor (Rf)*

The form factor (Rf) is a dimensionless ratio calculated by dividing the basin area by the square of the basin length. Basins with higher form factor values are more circular and tend to experience higher peak flows over shorter periods, whereas lower values indicate elongated basins. According to the analysis, sub-watersheds with form factor values greater than 0.3, such as SW-5, SW-7, SW-9, and SW-12, are considered elongated, while those with values below 0.3 exhibit more extended or stretched shapes.

➢ *Circularity Ratio (Cr)*

The circularity ratio (Cr) measures the relationship between the basin area and the area of a circle with the same perimeter. This ratio is influenced by several basin characteristics, including stream length, stream frequency, geological structures, land use/land cover, climate, and slope. The analysis shows that the circularity ratio of the sub-watersheds ranges from 0.12 to 0.38, indicating an elongated shape. This suggests that the sub-watersheds are composed of highly permeable and geologically homogeneous materials.

➢ *Elongation Ratio (Re)*

The elongation ratio (Re) ranges from 0.4 to 1.0 and reflects the basin's shape in relation to its climate and geological characteristics. Ratios closer to 1.0 indicate regions with gentle relief, while values between 0.6 and 0.8 suggest higher relief and steeper slopes. The elongation ratio analysis reveals that some sub-watersheds have values below 0.5, indicating elongated shapes with steep slopes and high relief. Sub-watersheds such as SW-3, SW-5, SW-6, SW-7, SW-9, SW-11, SW-12, SW-13, SW-14, and SW-16 have elongation ratios between 0.5 and 0.7, showing a more elongated form compared to the others.

➢ *Length of Overland Flow (Lo)*

The length of overland flow (Lo) is the distance water travels over the ground before concentrating into stream channels (Horton, 1945). This parameter is inversely related to drainage density and plays a crucial role in determining the hydrological and physiographic characteristics of a basin. Shorter overland flow lengths are associated with steeper slopes, while longer lengths correspond to gentler slopes. In this study, sub-watershed 6 has the highest overland flow length (0.68), indicating a higher potential for land degradation and erosion, while sub-watershed 1 has the lowest value (0.40), and suggesting minimal erosion susceptibility.

➢ *Compactness Coefficient (Cc)*

The compactness coefficient (Cc) measures the relationship between the basin area and its perimeter. From a hydrological perspective, a circular basin is most susceptible to peak flows due to the shortest concentration time. The compactness coefficient ranges from 1 (indicating a perfect circle) to less than 2 (indicating an elongated basin with lower peak flows over a longer duration). In this study, the compactness coefficient varies from 1.63 to 2.92, as detailed in Table 6.

- *Sub-Watershed Prioritization Based on Morphometric Parameters*

Sub-watershed prioritization is essential for effective watershed management, especially when resources are limited. This process should be based on the analysis of linear parameters, such as bifurcation ratio, drainage density, stream frequency, drainage texture ratio, and length of overland flow, as these are directly related to erodibility. On the other hand, basin shape parameters like form factor, circularity ratio, elongation ratio, and compactness coefficient are inversely related to erodibility. Prioritizing sub-watersheds with higher susceptibility to erosion allows for a more targeted and efficient treatment approach.

In this study, the prioritization of sub-watersheds was determined by evaluating the morphometric parameters of 16 sub-watersheds within the Panzara River basin. The sub-watersheds were classified into three priority levels: Low (Cp value 8 to 9), Moderate (Cp value 6.5 to 8), and High (Cp value 5 to 6.5). According to this classification, sub-watersheds SW-3, SW-4, SW-6, SW-7, and SW-9 fall under the highest priority category. Sub-watersheds SW-1, SW-10, SW-11, SW-13, and SW-15 are classified as moderate priority, while SW-2, SW-5, SW-8, SW-12, SW-14, and SW-16 are categorized as low priority. The prioritization scores for the Panzara sub-watersheds range from a maximum of 9.4 to a minimum of 5.2. Detailed rankings and prioritization results for all sixteen sub-watersheds are presented in Table 6.

- *Land Use/Land Cover (LULC) Analysis*

The land use and land cover analysis compare maps from 2000 and 2021, categorizing the landscape into five key classes: agricultural land, barren land, forest, water bodies, and settlements. These LULC maps, shown in Figure 8, highlight the positive and negative transformations in land resources over the study period. Additionally, the changes in LULC for each sub-watershed are presented in terms of area (in kilometers) and percentage, as detailed in Table 9.

- *Land Use/Land Cover Analysis in 2000*

The LULC map for 2000 was generated using Landsat 5 Thematic Mapper data. In 2000, the land use categories were as follows: Agriculture (85.99 km², 29.22% of the total watershed area), Forest (56.51 km², 19.20%), Waterbody (4.16 km², 1.41%), Barren land (130.85 km², 44.46%), and Settlements (16.77 km², 5.69%). These details are illustrated in Figure 5 and Table 7.

- *Land Use/Land Cover Analysis in 2021*

The LULC map for 2021 was created using Landsat 8 data. The analysis for 2021 revealed the following land use categories: Agriculture (104.36 km², 35.46% of the total watershed area), Forest (40.89 km², 13.89%), Waterbody (4.44 km², 1.51%), Barren land (124.28 km², 42.23%), and Settlements (20.31 km², 6.90%). These results are displayed in Figure 6 and Table 8.

- *Accuracy Assessment*

Accuracy assessment evaluates the reliability of satellite-derived data, calculating three types of accuracy: overall accuracy, producer accuracy, and user accuracy.

- *Accuracy Assessment and Kappa Coefficient for 2000 and 2021*

For the 2000 LULC, the overall accuracy was 81.8181%, with a Kappa coefficient of 0.772. Producer accuracy for categories Agriculture, Barren land, Forest, Waterbody, and Settlement were 91.67%, 86.67%, 61.54%, 93.33%, and 72.73%, respectively. User accuracy for these categories were 100%, 59.09%, 88.89%, 100%, and 80.00%, respectively. The details are shown in Tables i, ii, and iii.

In 2021, the LULC overall accuracy improved to 88.88%, with a Kappa coefficient of 0.85. Producer accuracy for the same five categories were 80.00%, 92.31%, 88.89%, 100.00%, and 83.33%, respectively. User accuracy for these categories were 88.89%, 85.71%, 88.89%, 90.91%, and 90.91%, respectively. These results are detailed in Tables iv, v, and vi.

- *Change Detection Between 2000 and 2021*

The change detection analysis between the LULC maps of 2000 and 2021 reveals both positive and negative changes within the watershed. Positive changes were observed in agricultural land (+6.24%), water bodies (+0.1%), and settlements (+1.21%). Negative changes were noted in forest (-5.31%) and barren land (-2.23%). This analysis indicates that the most significant positive change occurred in agricultural land, while the forest experienced the most substantial negative change. The results are presented in Figure 9 and Table 10.

- *LULC Change Detection in Sub-Watersheds*

For a more detailed analysis, the watershed was divided into sixteen sub-watersheds (SW1 to SW16). Each sub-watershed's LULC was analyzed to assess positive and negative changes, aiding in land resource conservation strategies. The LULC changes for each sub-watershed, both in absolute and percentage terms, are provided in Table 9.

- *Prioritization of Sub-Watersheds Based on LULC Categories*

Sub-watersheds were prioritized based on changes in key LULC features—agriculture, barren land, forest, water bodies, and settlements. The sub-watersheds were categorized into three priority classes: High (5-7), Moderate (7-9), and Low (9-11), based on the composite rank value. According to the LULC change analysis, SW-2, SW-12, SW-13, and SW-16 fall into the highest priority category, while SW-3, SW-4, SW-5, SW-7, SW-8, SW-11, and SW-14 are in the lowest priority group. The remaining sub-watersheds, SW-1, SW-6, SW-9, SW-10, and SW-15, are classified as moderate priority. These findings are shown in Table 9 and Figure 8.

- *Comparison of Prioritization Based on Morphometric and LULC Analyses*

The prioritization results from morphometric and LULC analyses were compared to identify common sub-watersheds within each priority class. The comparison shows that SW-1, SW-10, and SW-15 consistently fall under the moderate priority category, while SW-5, SW-8, and SW-14 are consistently ranked as low priority across both analyses. Interestingly, some sub-watersheds, such as those prioritized low based on 2000 LULC data, moved to a higher priority after the 2021 LULC change detection, and vice versa. This correlation, detailed in Table 10 and Figure 9, suggests that combining morphometric and LULC analyses provides a more reliable basis for preserving and sustaining watershed resources, particularly those affecting hydrological balance and erosion.

V. CONCLUSION

A GIS-based approach is not only faster but also more effective than traditional methods for watershed analysis. This study demonstrates that morphometric analysis yields dimensionless parameters that facilitate the comparison of a watershed with neighboring watersheds, aiding in decision-making for the construction of hydraulic structures to combat erosion. The results from morphometric and LULC analyses for each watershed provide critical insights for hydrologic engineers in planning and management.

The analysis of the sixteen sub-watersheds within the Panzara River basin reveals a strong correlation between morphometric characteristics and the watershed’s hydrologic response. The Panzara River basin is characterized by a rolling drainage surface, coarse drainage texture, and minimal slope variation in flatter areas. The sub-watersheds exhibit an elongated shape with highly permeable, homogeneous geologic materials, steep slopes, and high relief.

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The prioritization of sub-watersheds based on morphometric analysis indicates that SW-3, SW-4, SW-6, SW-7, and SW-9 are of the highest priority. Conversely, LULC analysis prioritizes sub-watersheds SW-2, SW-12, SW-13, and SW-16 as the most critical. The overall accuracy of the land use/land cover analysis was 81.82% for the year 2000 and improved to 88.88% in 2021. The Kappa coefficient, which measures agreement between observed and predicted classifications, was 0.772 for 2000 and increased to 0.85 in 2021.

The change detection analysis of LULC data from 2000 to 2021 highlights significant positive changes in agricultural land, while forest cover saw the smallest percentage decline. By integrating morphometric and LULC analyses, this study has effectively identified and characterized the unique attributes of each sub-watershed, providing valuable insights for the sustainable management of the watershed.

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Table 1 Morphometric Parameter, their Formula and References

Sr. No	Morphometric Parameter	Formula	Reference
1	Stream order (ψ)	Position of stream (hierarchical rank)	(STRAHLER 1952)
2	Number of streams (Nψ)	Nψ = N1 + N2 + N3… Nn	(HORTON 1945)
3	Stream length (Lψ) km	Lψ = L1 + L2 + L3… Ln	(STRAHLER 1952)
4	Mean stream length (L̦ψ) km	L̦ψ = Σ Lψ/Nψ	(HORTON 1945)
5	Bifurcation ratio (Rb)	Rb = Nψ/N (ψ + 1)	(Schumm 1956)
6	Mean bifurcation ratio (Rbm)	Average of all bifurcation ratio	(Strahler 1964)
7	Drainage density (Dd) km s−1	Dd = Σ Lψ/Ab where Ab is the basin area	(Horton 1932)
8	Stream frequency (Fs)	Fs = Σ Nψ/Ab where Ab is the basin area	(Horton 1932)
9	Texture ratio (Tr)	Tr(ψ) = Nψ/Pb (ψ = 1,2,3…n)	(Schumm 1956)
10	Form factor (Ff)	Ff = Ab/Lb2 where Lb is the basin length	(HORTON 1945)
11	Elongation ratio (Er)	Er = Dd/Lb where Lb is the basin length	(Schumm 1956)
12	Circularity ratio (Cr)	Cr = 12.56A/Pb2 where Pb is the basin perimeter	(Strahler 1964)
13	Compactness coefficient (Cc)	Cc = 0.2841 × Pb/Ab0.5 where Ab is the basin area	(Nooka Ratnam et al. 2005b)
14	Length of overland flow (Lo)	Lo = 1/2Dd	(HORTON 1945)

Table 2 Sub-Watershed Wise Stream Order with a Total Number of Segments (Nu)

Sr. No.	Sub-Watershed	Area (Km^2)	Stream Order (u)					Total number
			1	2	3	4	5	
1	SW-1	338	116	28	5	2	0	150
2	SW-2	130	41	10	1	0	0	52
3	SW-3	309	106	30	6	1	0	143
4	SW-4	304	92	33	7	4	1	137
5	SW-5	177	53	18	2	1	1	75
6	SW-6	182	70	23	7	2	1	103
7	SW-7	158	50	18	3	1	0	72
8	SW-8	71	19	3	1	1	1	25
9	SW-9	191	63	18	4	1	1	87
10	SW-10	150	46	10	3	1	1	61
11	SW-11	231	72	12	5	1	1	91
12	SW-12	183	57	15	3	1	1	77
13	SW-13	182	55	21	5	2	1	84
14	SW-14	124	41	9	4	1	0	55
15	SW-15	62	18	3	1	2	1	25
16	SW-16	150	43	10	2	1	1	57
Total	-	2942	942	261	59	21	11	1294
Percentage	-	-	72.79	20.17	4.56	1.62	0.85	100

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Table 3 Sub-Watershed Wise Stream Order with Stream Length (Lu)

Sr. No.	**Sub-Watershed**	**Area (Km^2)**	**Stream Order Length (Lu) Km.**					**Total of stream length**
			1	**2**	**3**	**4**	**5**	
1	SW-1	338	148	61	27	32	0	268
2	SW-2	130	67	19	20	0	0	106
3	SW-3	309	130	69	67	26	0	292
4	SW-4	304	168	92	49	68	13	390
5	SW-5	177	88	38	10	15	0.02	151
6	SW-6	182	106	66	13	38	23	246
7	SW-7	158	84	60	12	9	0	165
8	SW-8	71	25	26	10	9	1	71
9	SW-9	191	107	64	20	13	16	220
10	SW-10	150	76	37	44	13	10	180
11	SW-11	231	122	39	44	19	6	230
12	SW-12	183	98	34	27	6	6	171
13	SW-13	182	92	61	22	21	16	212
14	SW-14	124	51	31	25	6	0	113
15	SW-15	62	32	14	4	13	15	78
16	SW-16	150	64	29	13	7	10	123
Total	-	2942	1458	740	407	295	116.02	3016
Percentage	-	-	48.34	24.54	13.49	9.78	3.85	100

Table 4 Sub-Watershed Wise Stream Order with Mean Stream Length Ratio (LSM)

Sr. No.	**Sub-basin**	**Mean Stream Length Ratio (LSM)**					**Mean Ratio (LSM)**
		II/I	**III/II**	**IV/III**	**V/IV**	**VI/V**	
1	SW1	0.41	0.44	1.19	0.00	-	0.51
2	SW2	0.28	1.05	0.00	0.00	-	0.33
3	SW3	0.53	0.97	0.39	0.00	-	0.47
4	SW4	0.55	0.53	1.39	0.19	-	0.66
5	SW5	0.43	0.26	1.50	0.00	-	0.55
6	SW6	0.62	0.20	2.92	0.61	-	1.09
7	SW7	0.71	0.20	0.75	0.00	-	0.42
8	SW8	1.04	0.38	0.90	0.11	-	0.61
9	SW9	0.60	0.31	0.65	1.23	-	0.70
10	SW10	0.49	1.19	0.30	0.77	-	0.69
11	SW11	0.32	1.13	0.43	0.32	-	0.55
12	SW12	0.35	0.79	0.22	1.00	-	0.59
13	SW13	0.66	0.36	0.95	0.76	-	0.69
14	SW14	0.61	0.81	0.24	0.00	-	0.41
15	SW15	0.44	0.29	3.25	1.15	-	1.28
16	SW16	0.45	0.45	0.54	1.43	-	0.72
Total		8.50	9.37	15.62	7.57	0.00	10.26
Mean Stream Length		0.53	0.58	0.97	0.47	0	0.64

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Table 5 Sub-Watershed Wise Bifurcation Ratio (Rb)

Sr. No.	Sub-Watershed	Bifurcation Ratio (Rb)					Mean Bifurcation Ratio (RBM)
		I/II	II/III	III/IV	IV/V	V/VI	
1	SW1	4.14	5.60	5.00	-	-	4.91
2	SW2	4.10	10.00	5.00	0.00	-	4.78
3	SW3	3.53	5.00	6.00	-	-	4.84
4	SW4	2.79	4.71	1.75	4.00	-	3.31
5	SW5	2.94	9.00	2.00	1.00	-	3.74
6	SW6	3.04	3.29	3.50	2.00	-	2.96
7	SW7	2.78	6.00	3.00	-	-	3.93
8	SW8	6.33	3.00	1.00	1.00	-	2.83
9	SW9	3.50	4.50	4.00	1.00	-	3.25
10	SW10	4.60	3.33	3.00	1.00	-	2.98
11	SW11	6.00	2.40	5.00	1.00	-	3.60
12	SW12	3.80	5.00	3.00	1.00	-	3.20
13	SW13	2.62	4.20	2.50	2.00	-	2.83
14	SW14	4.56	2.25	4.00	-	-	3.60
15	SW15	6.00	3.00	0.50	2.00	-	2.88
16	SW16	4.30	5.00	2.00	1.00	-	3.77

Table 6 Estimated Compound Parameter with Priority Ranking

SW	Dd	Fs	Rbm	Rt	Lo	Re	Cr	Rf	Cc	CP	Ranking	Priority
SW1	0.79	0.44	4.91	0.89	0.40	0.36	0.15	0.10	2.61			
	14	**4**	**1**	**6**	**12**	**2**	**3**	**2**	**13**	**7.1**	**6**	**MODERATE**
SW2	0.82	0.40	4.78	0.54	0.41	0.42	0.18	0.14	2.39			
	13	**7**	**3**	**13**	**11**	**4**	**5**	**4**	**11**	**8.4**	**13**	**LOW**
SW3	0.94	0.46	4.84	1.24	0.47	0.57	0.29	0.25	1.86			
	9	**2**	**2**	**1**	**8**	**8**	**11**	**8**	**3**	**6**	**3**	**HIGH**
SW4	1.28	0.45	3.31	1.01	0.64	0.46	0.21	0.16	2.20			
	2	**3**	**6**	**2**	**2**	**5**	**7**	**5**	**9**	**5.2**	**1**	**HIGH**
SW5	0.85	0.42	3.74	0.78	0.43	0.63	0.24	0.31	2.05			
	12	**5**	**5**	**10**	**10**	**11**	**9**	**11**	**5**	**8.2**	**11**	**LOW**
SW6	1.35	0.57	2.96	0.96	0.68	0.54	0.20	0.23	2.25			
	1	**1**	**12**	**5**	**1**	**7**	**6**	**7**	**10**	**5.9**	**2**	**HIGH**
SW7	1.04	0.46	3.93	1.00	0.52	0.64	0.38	0.33	1.63			
	6	**2**	**4**	**3**	**6**	**12**	**13**	**13**	**1**	**6.2**	**4**	**HIGH**
SW8	1	0.35	2.83	0.31	0.5	0.32	0.14	0.08	2.70			
	8	**10**	**14**	**14**	**7**	**1**	**2**	**1**	**14**	**8.6**	**15**	**LOW**
SW9	1.15	0.46	3.25	0.97	0.58	0.68	0.30	0.36	1.85			
	5	**2**	**7**	**4**	**5**	**13**	**12**	**14**	**2**	**6.5**	**5**	**HIGH**
SW10	1.2	0.41	2.98	0.66	0.6	0.41	0.22	0.13	2.13			
	7	**6**	**11**	**11**	**4**	**3**	**8**	**3**	**7**	**7.4**	**8**	**MODERATE**
SW11	1	0.39	3.6	0.83	0.5	0.52	0.24	0.21	2.06			
	8	**8**	**9**	**9**	**7**	**6**	**9**	**6**	**6**	**7.8**	**10**	**MODERATE**
SW12	0.93	0.42	3.2	0.85	0.47	0.64	0.28	0.32	1.91			
	10	**5**	**10**	**8**	**8**	**12**	**10**	**12**	**4**	**8.2**	**12**	**LOW**
SW13	1.16	0.46	2.83	0.86	0.58	0.61	0.24	0.29	2.06			
	4	**2**	**14**	**7**	**5**	**10**	**9**	**10**	**6**	**7.2**	**7**	**MODERATE**
SW14	0.91	0.44	3.6	0.65	0.46	0.57	0.22	0.26	2.17			
	11	**4**	**9**	**12**	**9**	**8**	**8**	**9**	**8**	**8.5**	**14**	**LOW**
SW15	1.26	0.40	2.88	0.31	0.63	0.42	0.12	0.14	2.92			
	3	**7**	**13**	**14**	**3**	**4**	**1**	**4**	**15**	**7.6**	**9**	**MODERATE**
SW16	0.82	0.38	3.08	0.54	0.41	0.58	0.17	0.26	2.44			
	13	**9**	**8**	**13**	**11**	**9**	**4**	**9**	**12**	**9.4**	**16**	**LOW**

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Table 7 Land use/ Land Cover Area Statistics of Panzara River Sub-Watershed for the Year 2000

SW	Area	Land cover categories					Total
		Agriculture	Barren Land	Forest	Waterbody	Settlement	
SW-1	Km^2 (%)	78.01 (23.02)	160.2 (47.27)	86.68 (25.58)	1.91 (0.56)	12.09 (3.57)	338.89 (100)
SW-2	Km^2 (%)	23.23 (17.94)	78.78 (60.84)	25.88 (19.99)	0.13 (0.10)	1.45 (1.12)	129.48 (100)
SW-3	Km^2 (%)	54.51 (17.66)	172.04 (55.74)	73.39 (23.77)	2.23 (0.72)	6.50 (2.11)	308.67 (100)
SW-4	Km^2 (%)	95.62 (31.43)	133.73 (43.96)	59.48 (19.55)	1.66 (0.54)	13.74 (4.52)	304.23 (100)
SW-5	Km^2 (%)	24.16 (13.71)	110.46 (62.66)	32.01 (18.16)	0.91 (0.52)	8.73 (4.95)	176.27 (100)
SW-6	Km^2 (%)	49.61 (27.23)	68.11 (37.39)	45.3 (24.87)	3.65 (2.00)	15.50 (8.51)	182.17 (100)
SW-7	Km^2 (%)	50.59 (32.11)	73.58 (46.70)	26.73 (16.97)	0.44 (0.28)	6.22 (3.95)	157.56 (100)
SW-8	Km^2 (%)	6.91 (9.79)	51.1 (72.38)	7.21 (10.22)	1.75 (2.47)	3.63 (5.14)	70.6 (100)
SW-9	Km^2 (%)	53.85 (28.16)	100.5 (52.55)	22.92 (11.98)	3.27 (1.71)	10.70 (5.60)	191.24 (100)
SW-10	Km^2 (%)	25.41 (16.97)	85.64 (57.20)	17.18 (11.47)	2.45 (1.64)	19.03 (12.71)	149.71 (100)
SW-11	Km^2 (%)	69.06 (29.96)	92.85 (40.28)	49.77 (21.59)	1.36 (0.59)	17.46 (7.58)	230.5 (100)
SW-12	Km^2 (%)	49.83 (27.20)	75.11 (41.00)	37.69 (20.58)	2.24 (1.22)	18.30 (9.99)	183.17 (100)
SW-13	Km^2 (%)	99.86 (55.05)	39.29 (21.66)	29.56 (16.29)	3.46 (1.91)	9.24 (5.09)	181.41 (100)
SW-14	Km^2 (%)	30.67 (24.66)	56.54 (45.47)	13.53 (10.88)	9.20 (7.40)	14.41 (11.59)	124.34 (100)
SW-15	Km^2 (%)	36.74 (59.12)	12.01 (19.32)	7.57 (12.18)	3.35 (5.39)	2.48 (3.99)	62.13 (100)
SW-16	Km^2 (%)	118.56 (79.05)	14.29 (9.53)	12.72 (8.48)	2.24 (1.49)	2.17 (1.45)	149.98 (100)

Table 8 Land use/ Land Cover Area Statistics of Panzara River Sub-Watershed for the Year 2021

SW	Area	Land cover categories					Total
		Agriculture	Barren Land	Forest	Waterbody	Settlement	
SW-1	Km^2(%)	90.25 (26.69)	169.83 (50.22)	61.26 (18.11)	2.30 (0.68)	14.55 (4.30)	338.19 (100)
SW-2	Km^2(%)	15.97 (12.33)	84.28 (65.09)	25.14 (19.42)	1.29 (1.00)	2.80 (2.17)	129.49 (100)
SW-3	Km^2(%)	39.71 (12.86)	133.63 (43.29)	124.19 (40.24)	4.09 (1.33)	7.03 (2.28)	308.66 (100)
SW-4	Km^2(%)	85.81 (28.21)	104.24 (34.27)	99.49 (32.71)	2.12 (0.70)	12.54 (4.12)	304.21 (100)
SW-5	Km^2(%)	41.48 (23.54)	97.80 (55.49)	27.04 (15.34)	2.33 (1.32)	7.61 (4.32)	176.26 (100)
SW-6	Km^2(%)	71.52 (39.26)	72.63 (39.86)	15.48 (8.50)	9.21 (5.06)	13.34 (7.32)	182.19 (100)
SW-7	Km^2(%)	67.83 (43.05)	64.77 (41.11)	17.96 (11.40)	0.89 (0.56)	6.09 (3.87)	157.55 (100)
SW-8	Km^2(%)	12.47 (17.67)	50.36 (71.34)	2.74 (3.88)	1.69 (2.39)	3.33 (4.72)	70.59 (100)
SW-9	Km^2(%)	66.41 (34.72)	101.52 (53.09)	8.97 (4.69)	6.21 (3.25)	8.13 (4.25)	191.24 (100)
SW-10	Km^2(%)	40.27 (26.90)	75.99 (50.76)	1.03 (0.69)	3.34 (2.23)	29.08 (19.42)	149.71 (100)
SW-11	Km^2(%)	113.29 (49.15)	94.74 (41.10)	7.02 (3.05)	1.39 (0.60)	14.06 (6.10)	230.52 (100)
SW-12	Km^2(%)	74.36 (40.59)	73.03 (39.87)	5.94 (3.24)	3.18 (1.73)	26.68 (14.56)	183.18 (100)
SW-13	Km^2(%)	116.79 (64.38)	47.51 (26.19)	3.45 (1.90)	0.89 (0.49)	12.77 (7.04)	181.41 (100)
SW-14	Km^2(%)	48.14 (38.72)	53.47 (43.00)	0.93 (0.75)	3.31 (2.66)	18.48 (14.86)	124.34 (100)
SW-15	Km^2(%)	42.70 (68.73)	7.09 (11.41)	0.54 (0.88)	1.09 (1.75)	10.71 (17.24)	62.13 (100)
SW-16	Km^2(%)	120.02 (80.03)	19.82 (13.22)	1.45 (0.97)	0.67 (0.45)	7.99 (5.33)	149.96 (100)

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Table (i) Error Matrix Resulting from Classifying Training Set Pixels.

Land-Cover	**Agriculture**	**Barren land**	**Forest**	**Waterbody**	**Settlement**	**Total**
Agriculture	**11**	0	0	0	0	11
Barren land	1	**13**	4	1	3	22
Forest	0	1	**8**	0	0	9
Waterbody	0	0	0	**14**	0	14
Settlement	0	1	1	0	**8**	10
Total	12	15	13	15	11	**66**

Table (ii) Error Matrix (User Accuracy) Resulting from Classifying Training Set Pixels

User accuracy	**Land cover**	**Correct Classified Pixel**	**Reference Pixel**	**Percent**
	Agriculture	11	11	100.00
	Barren land	13	22	59.09
	Forest	8	9	88.89
	Waterbody	14	14	100.00
	Settlement	8	10	80.00

Table (iii) Error Matrix ((Producer Accuracy) Resulting from Classifying Training Set Pixels

Producer Accuracy	**Land cover**	**Correct Classified Pixel**	**Reference Pixel**	**Percent**
	Agriculture	11	12	91.67
	Barren land	13	15	86.67
	Forest	8	13	61.54
	Waterbody	14	15	93.33
	Settlement	8	11	72.73

Table (iv) Error Matrix Resulting from Classifying Training Set Pixels.

Land Cover	**Agriculture**	**Barren land**	**Forest**	**Waterbody**	**Settlement**	**Total**
Agriculture	**8**	0	1	0	0	9
Barren land	1	**12**	0	0	1	14
Forest	1	0	**8**	0	0	9
Waterbody	0	0	0	**10**	1	11
Settlement	0	1	0	0	**10**	11
Total	10	13	9	10	12	**54**

Table (v) Error Matrix (User Accuracy) Resulting from Classifying Training Set Pixels

User accuracy	**Land Cover**	**Correct classified pixel**	**Reference Pixel**	**Percent**
	Agriculture	8	9	88.89
	Barren land	12	14	85.71
	Forest	8	9	88.89
	Waterbody	10	11	90.91
	Settlement	10	11	90.91

Table (vi) Error Matrix ((Producer Accuracy) Resulting from Classifying Training Set Pixels

Producer Accuracy	**Land Cover**	**Correct classified pixel**	**Reference Pixel**	**Percent**
	Agriculture	8	10	80.00
	Barren land	12	13	92.31
	Forest	8	9	88.89
	Waterbody	10	10	100.00
	Settlement	10	12	83.33

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Table 9 Prioritization of Sub-Watersheds Based on the LULC Category

	A	BL	F	W	S	CP	PRIORITY	RANK
SW1	3.67	2.94	-7.46	0.12	0.73	**7.2**	**MODERATE**	**6**
	5	**4**	**9**	**10**	**8**			
SW2	-5.61	4.24	-0.57	0.9	1.04	**5.4**	**HIGH**	**1**
	1	**2**	**14**	**3**	**7**			
SW3	-4.80	-12.44	16.46	0.6	0.17	**9.6**	**LOW**	**10**
	2	**16**	**16**	**5**	**9**			
SW4	-3.22	-9.69	13.16	0.15	-0.39	**10.6**	**LOW**	**16**
	3	**15**	**15**	**9**	**11**			
SW5	9.83	-7.18	-2.82	0.8	-0.64	**10.6**	**LOW**	**15**
	10	**13**	**13**	**4**	**13**			
SW6	12.02	2.47	-16.37	3.06	-1.19	**7.2**	**MODERATE**	**5**
	13	**5**	**3**	**1**	**14**			
SW7	10.95	-5.58	-5.56	0.28	-0.08	**10.6**	**LOW**	**14**
	12	**11**	**12**	**8**	**10**			
SW8	7.89	-1.04	-6.34	-0.08	-0.42	**10**	**LOW**	**11**
	7	**8**	**11**	**12**	**12**			
SW9	6.57	0.54	-7.29	1.53	-1.34	**8**	**MODERATE**	**8**
	6	**7**	**10**	**2**	**15**			
SW10	9.93	-6.44	-10.79	0.59	6.71	**7.4**	**MODERATE**	**7**
	11	**12**	**6**	**6**	**2**			
SW11	19.19	0.82	-18.54	0.01	-1.48	**10**	**LOW**	**12**
	16	**6**	**1**	**11**	**16**			
SW12	13.39	-1.14	-17.34	0.51	4.57	**7**	**HIGH**	**4**
	14	**9**	**2**	**7**	**3**			
SW13	9.33	4.53	-14.39	-1.42	1.95	**6.6**	**HIGH**	**3**
	8	**1**	**4**	**14**	**6**			
SW14	14.05	-2.46	-10.13	-4.73	3.28	**10.6**	**LOW**	**13**
	15	**10**	**7**	**16**	**5**			
SW15	9.61	-7.91	-11.3	-3.64	13.25	**8.8**	**MODERATE**	**9**
	9	**14**	**5**	**15**	**1**			
SW16	0.98	3.69	-7.51	-1.05	3.89	**6**	**HIGH**	**2**
	4	**3**	**6**	**13**	**4**			

Table 10 Prioritization of Sub-Watershed (Morphometric and LULC Analysis)

Sub-Watershed	Priority of Morphometry (Rank)	Priority of LULC (Rank)
SW-1	**MODERATE (6)**	**MODERATE (6)**
SW-2	LOW (13)	HIGH (1)
SW-3	HIGH (3)	LOW (10)
SW-4	HIGH (1)	LOW (16)
SW-5	**LOW (11)**	**LOW (15)**
SW-6	HIGH (2)	MODERATE (5)
SW-7	HIGH (4)	LOW (14)
SW-8	**LOW (15)**	**LOW (11)**
SW-9	HIGH (5)	MODERATE (8)
SW-10	**MODERATE (8)**	**MODERATE (7)**
SW-11	MODERATE (10)	LOW (12)
SW-12	LOW (12)	HIGH (4)
SW-13	MODERATE (7)	HIGH (3)
SW-14	**LOW (14)**	**LOW (13)**
SW-15	**MODERATE (9)**	**MODERATE (9)**
SW-16	LOW (16)	HIGH (2)

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LIST OF FIGURE

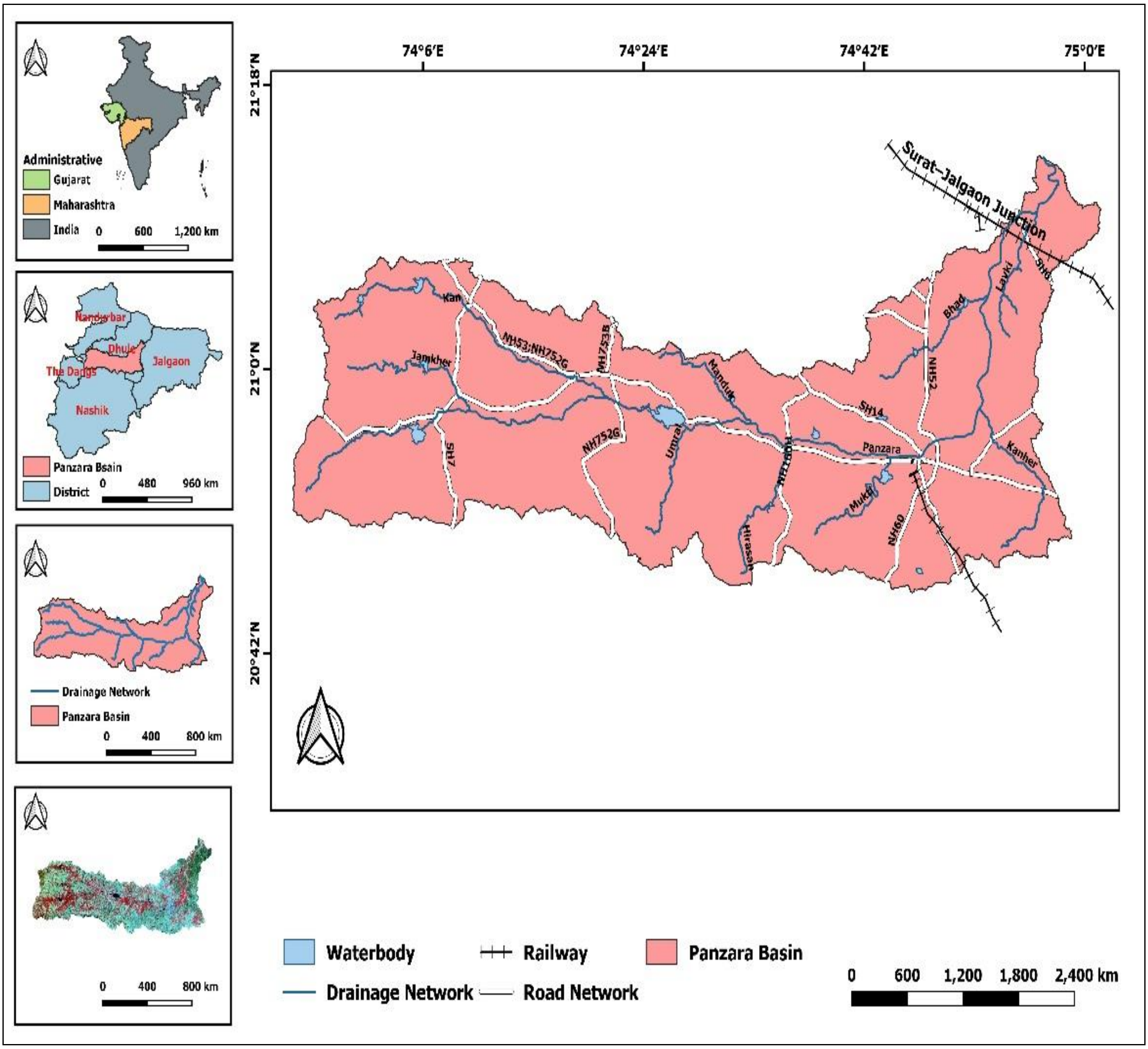

Fig 1 Study Area of Panzara River Basin

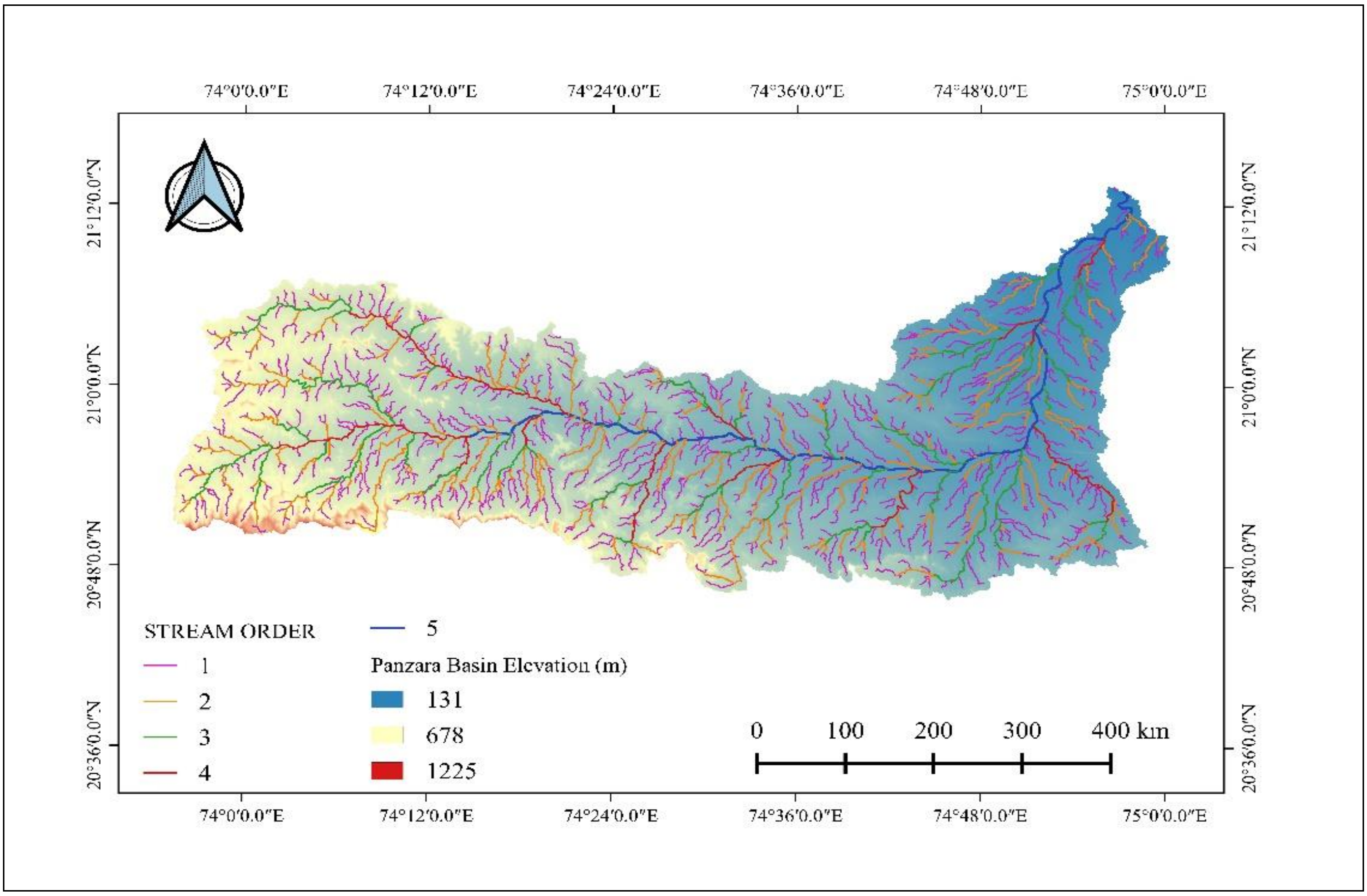

Fig 2 Stream Order of Panzara River Basin

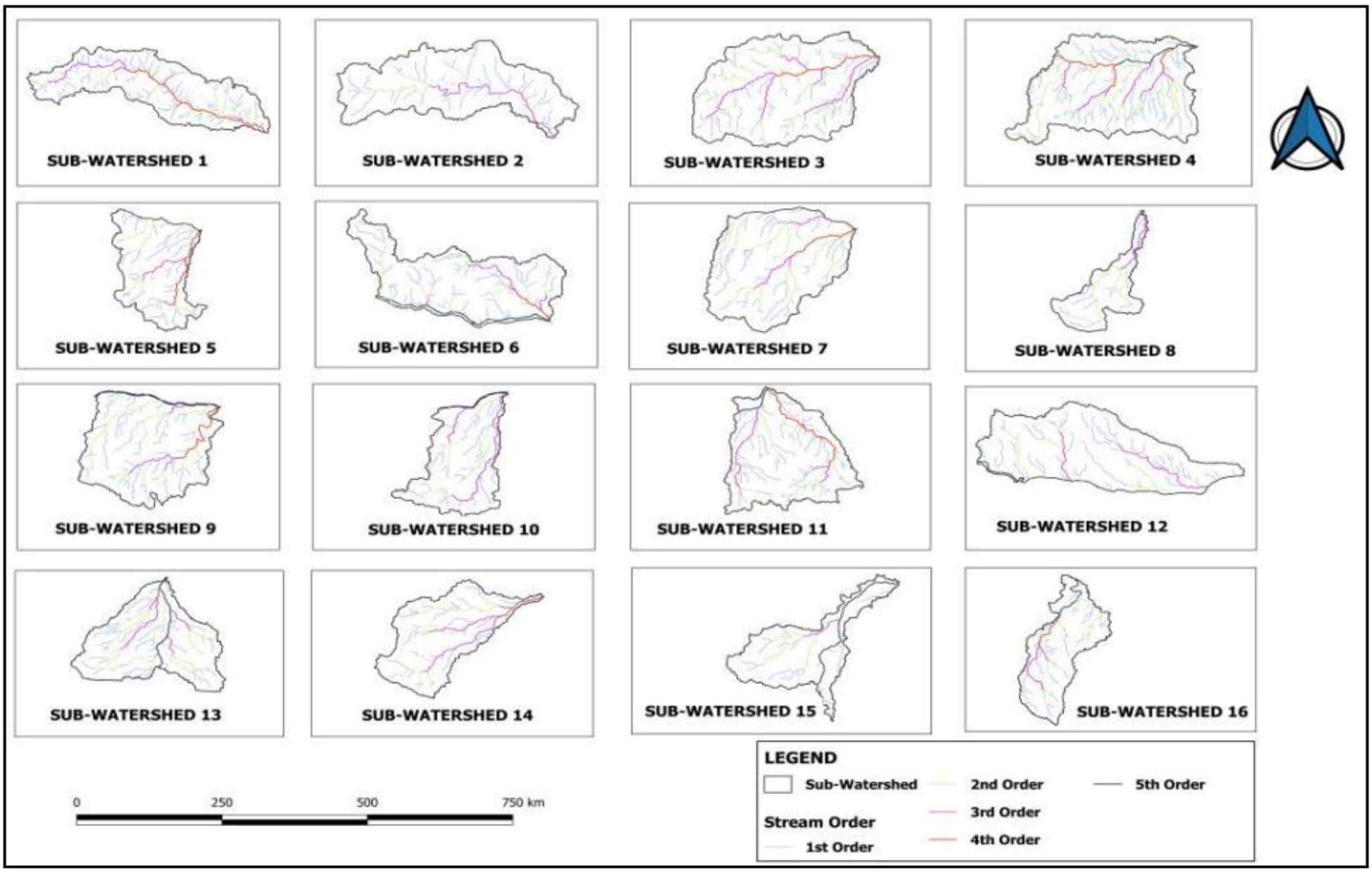

Fig 3 Stream Order of all Sub-Watersheds

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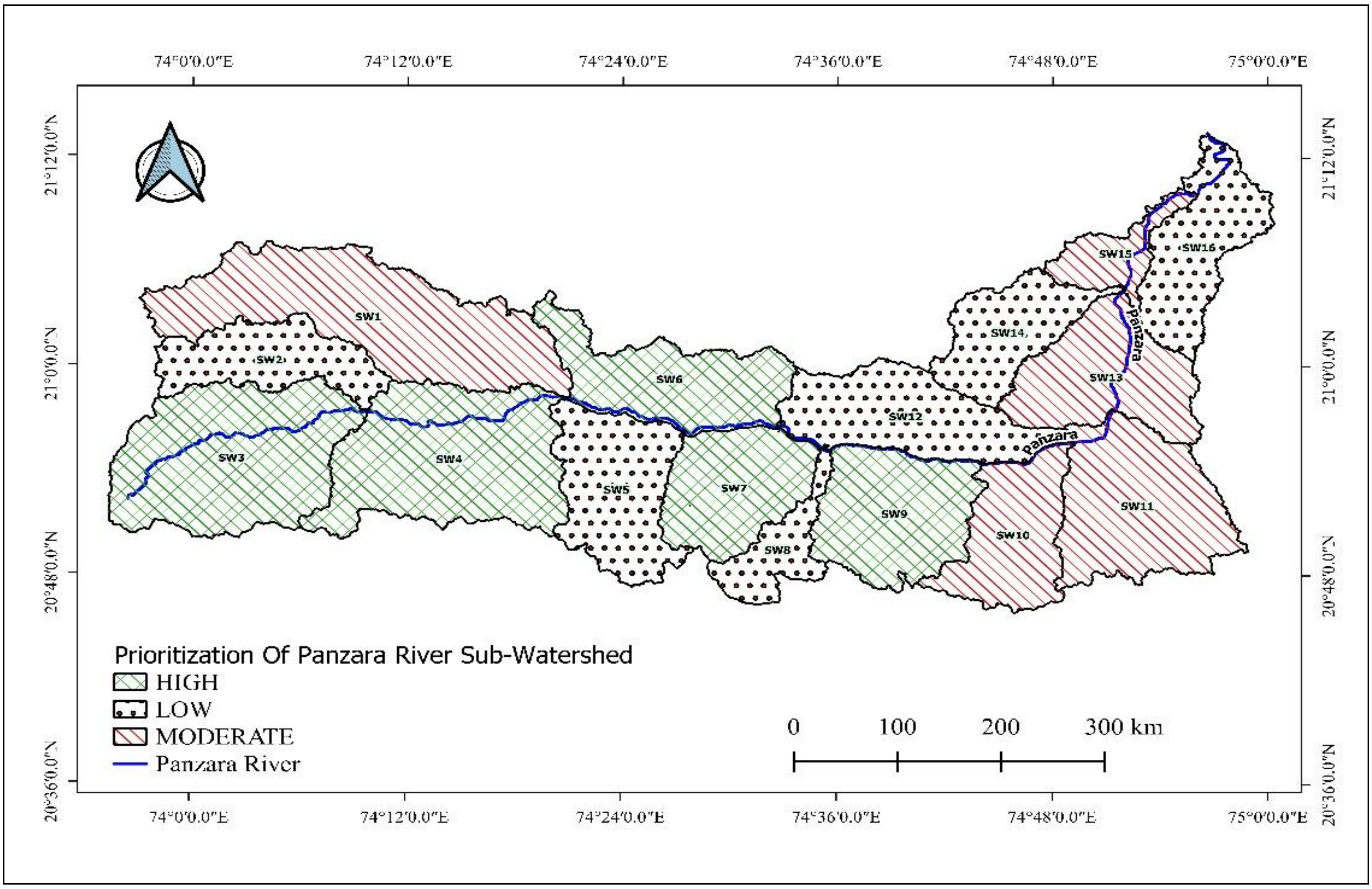

Fig 4 Map of Priority Sub-Watershed According to Morphometry of Watershed

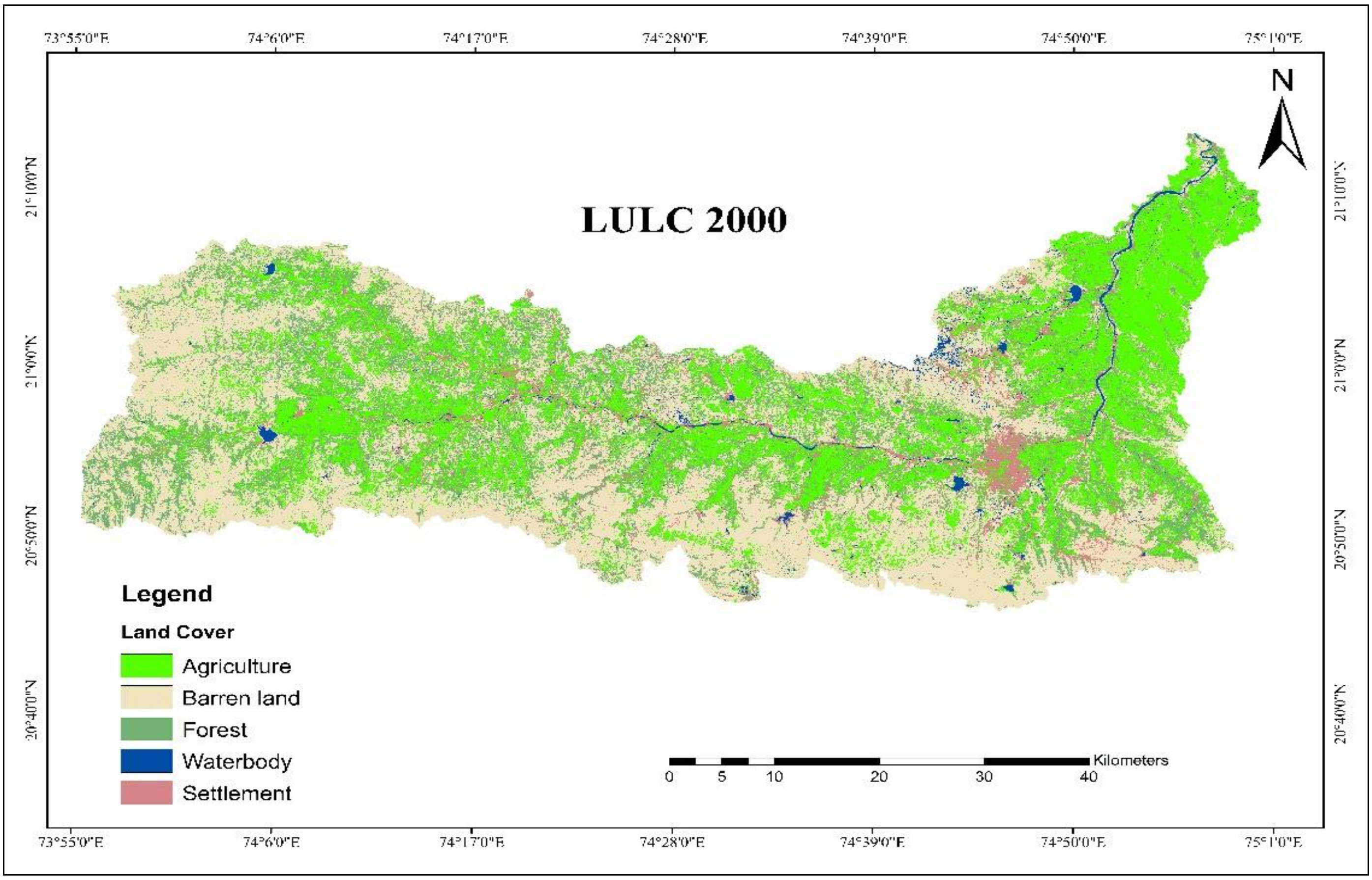

Fig 5 Land use/ Landcover Analysis for Basin 2000

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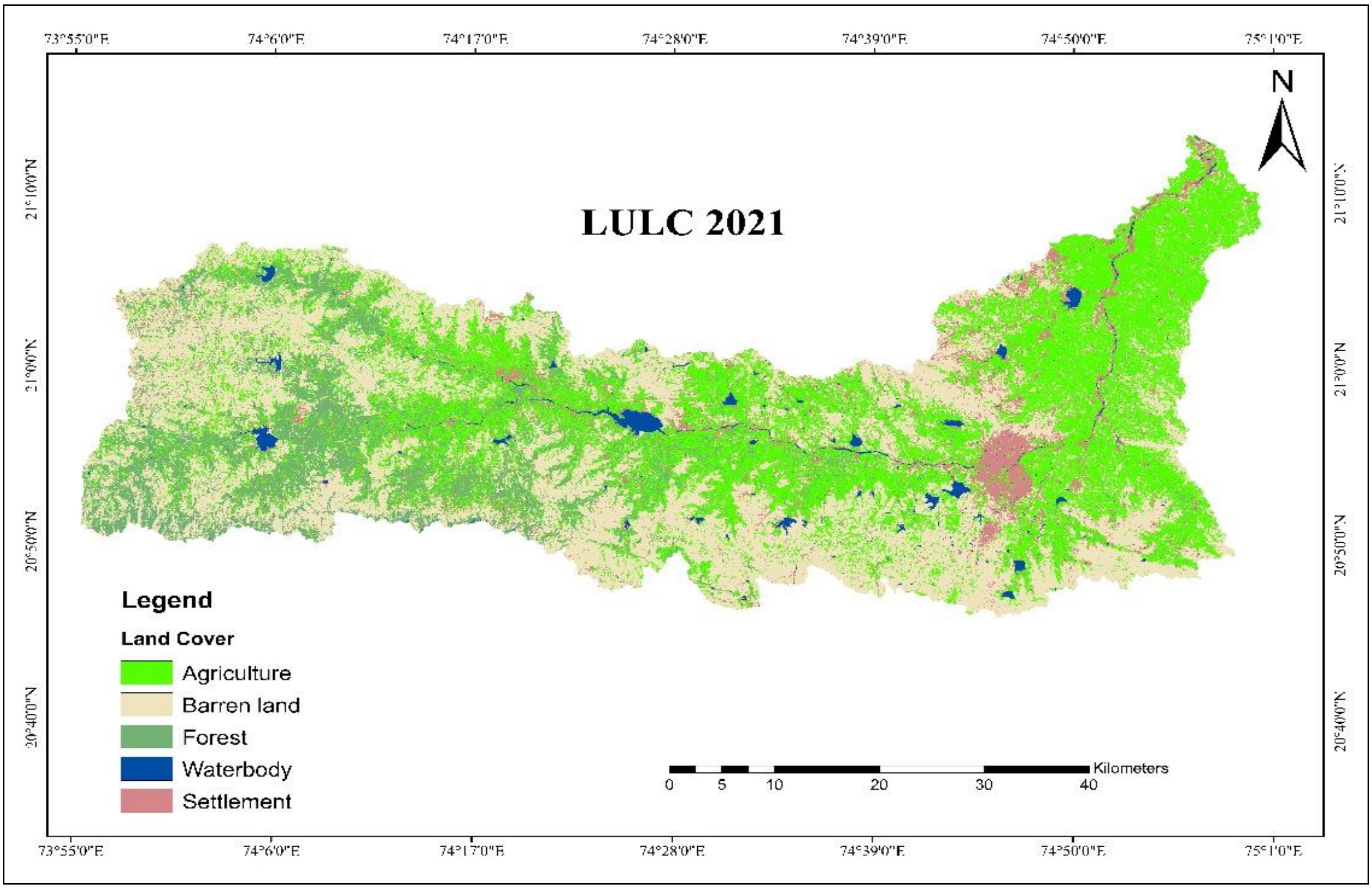

Fig 6 Land use/ Landcover Analysis for Basin 2021

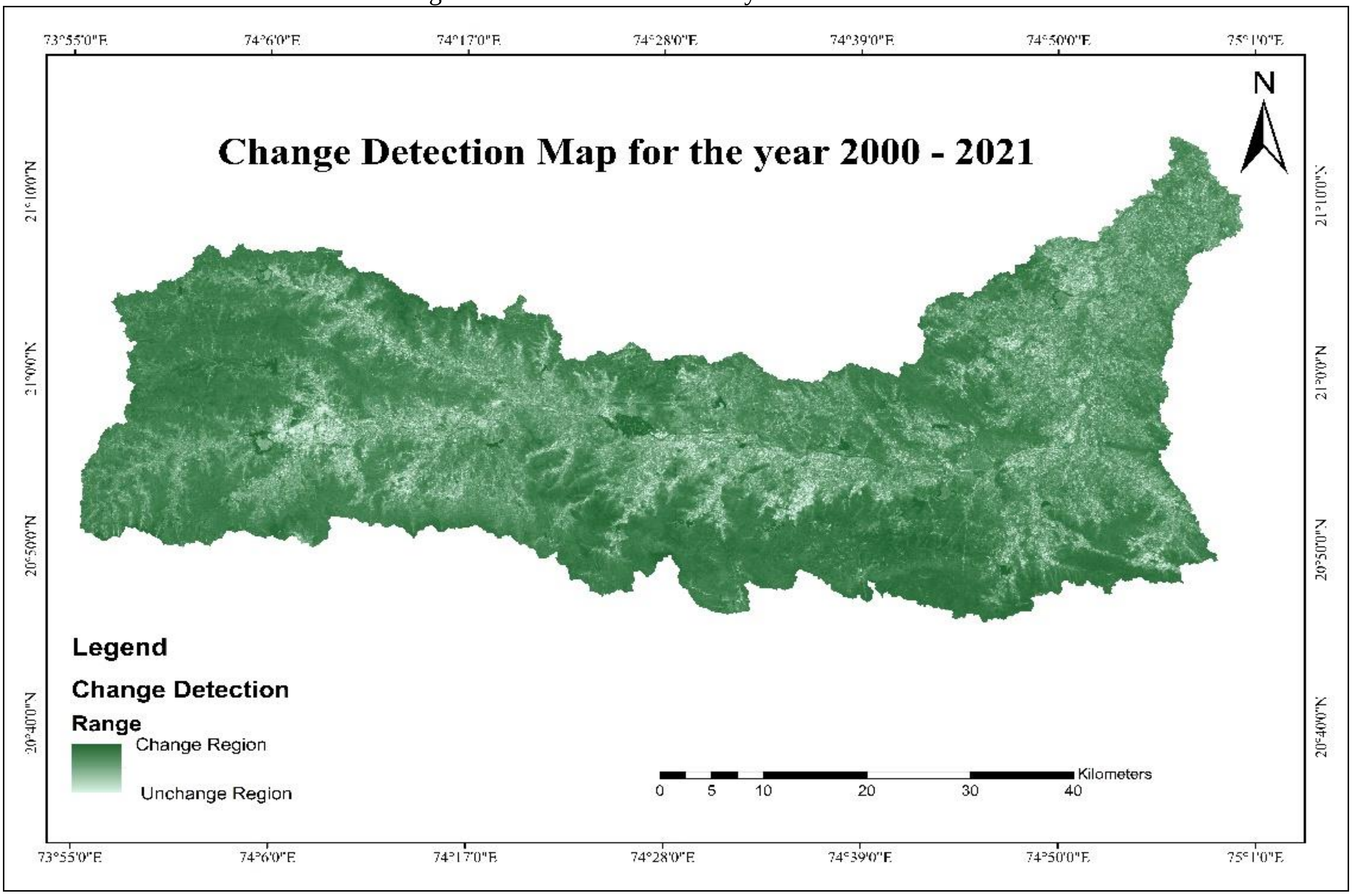

Fig 7 Change Detection LULC Map for the Year 2000 and 2021

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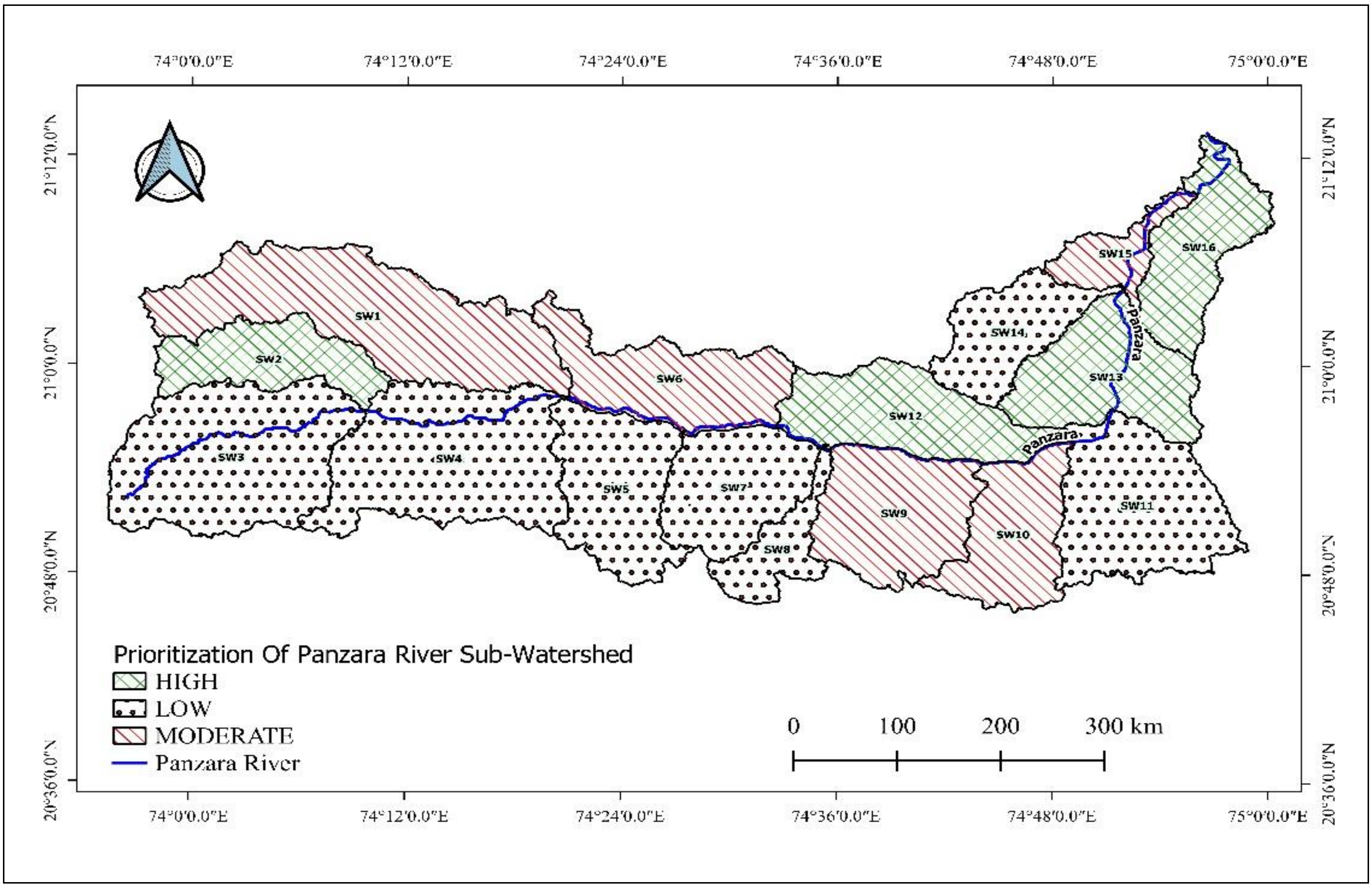

Fig 8 Prioritization of Sub-Watersheds based on the LULC Category

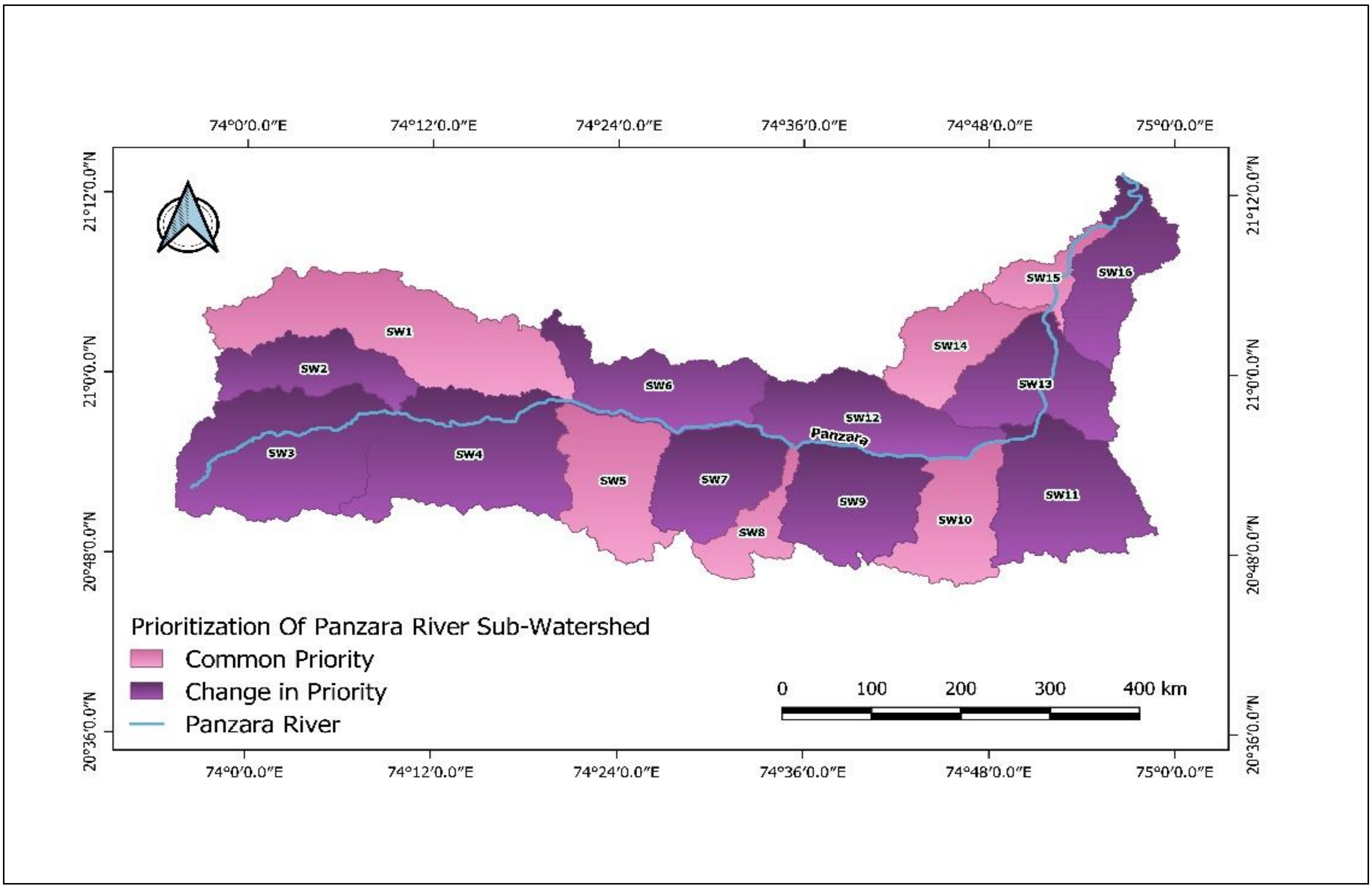

Fig 9 Comparison of Prioritization of Morphometric Analysis and Land use/Land Cover Analysis