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Geomorphic Analysis of Shardu River Watershed in Chure Landscape of Nepal

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Abstract

The landscape that forms the river basin and its geomorphologic characteristics are intertwined. The Chure Mountain is the youngest and the most fragile member of the Nepal landscape. Numerous rivers originate and flow through the Chure landscape. Understanding and analyzing the basin characteristics are vital to the sustainable management of the Chure landscape. In this regard, the present study aims to gain insight into basin characteristics, landuse, sediment properties, and river morphology of the Shardu river basin in the Chure landscape. The analysis is based on the data derived from satellite imagery, Digital elevation model, climate-related data, etc. Sediment sampling and suspended sediment concentration samples were measured from the field and analyses were carried out in the laboratory. It was observed that the landuse practice, structural intervention, sediment mining from a river bed, watershed dynamics, etc. have led to the instability of river morphology. The erosion and deposition at the upper and the lower reaches respectively of the Chure river basin depict a multi-dimensional discipline of its management. It is thus recommended that appropriate scientific practices and management approaches be adopted for the sustainability of the river and its watershed in Chure landscape.

Keywords

Basin characteristics, Chure landscape, river morphology, Sediment Grading, watershed management

1. Introduction

The sustainable use and management of rivers face dynamic challenges of river morphologies and frequent water-induced disasters like landslides, debris flow, and sedimentation. The Chure River basin significantly has loosely consolidated and soft rock which coupled with the basin shape and vulnerable to flooding during heavy rainfall[1]. The local geomorphology, climate pattern, and different spatial natural disturbance reflect the stream and river characteristics [2]. The alternative rotation of flood in summer and dry season in winter in the Chure region significantly affect river morphology [3]. The engineers working in river training management must have a thorough knowledge of river morphology as well as basic professional acumen to solve problems and construct hydraulic structures [4]. The various hydraulic infrastructure design used for watershed management in Nepal is based on Indian norms, which weren't intended for rivers with rapid variations in particle size distribution and dynamic morphology but rather for more typical alluvial rivers and may not always be suitable in Nepalese Chure rivers. Several river processes cause sediment to scour in the river: bank erosion, bend scour, confluence scour, protrusion scours, and avulsion [5]. The several principles and elements, such as increasing sediment supply, increasing sediment calibers, and rising channel gradient, affect the river morphology of alluvial rivers [6]. There is a murky relationship between typical sediment properties and how it affects channel shape. The imbalanced river morphological regime resulted from an excessive sediment yield [7]. This paper aims to analyze the data obtained from different primary and secondary sources to investigate basin characteristics, sediment characteristics, and river morphology patterns in the Shardu River basin for sustainable management of Chure Rivers. To better understand how basin characteristics and river sediment grading relate to river morphology in the Chure Landscape of Nepal, and it relates to the management of watersheds, this research will look at such topics.

2. Study Area

The Sharda River Basin stretches from 26°47'40" to 26°52'30.95" N and 87°13'20" to 87°19'20.15" E. The Middle Hill and Siwalik Hills are where the Shardu River rises and is regarded as a classless river. Administratively, it is situated in the Sunsari district of Koshi province of Nepal. The Shardu River's basins cover a total area of around 24.925 km2 having elevation ranges varying from 1589m to 221 m from mean sea level. The river basin's boundaries were marked on the basin map (Figure 1). The Terai Plain's basin boundary was drawn after taking into account the area's existing road systems, irrigation canals, and circular things like drainage pipes. On topographic maps with a scale of 1/1,00,000, general basin maps of the Shardu River are shown. The Shardu river basin has the following noteworthy characteristics: The river's velocity is higher due to the bed slope, which is steeper than that of the other rivers in the Terai plain by a factor of 50 to 500.

3. Material and Instrumentation

3.1 Data Required and Methods

The study was conducted by a combination of sampling, field visits, and secondary data available from different sources as

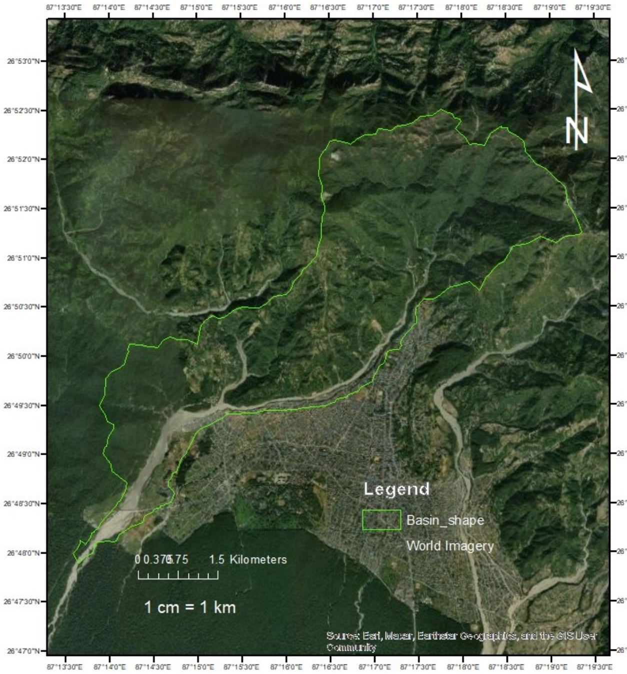

Figure 1: Study area map

explained below in Table 1. The primary datasets needed information on sediment size variation, topography, and river morphology where as secondary data for the geology of the basin, rainfall, drainage characteristics, and landuse pattern. The overall design outcome of basin characteristics, sediment size variation, and river morphology related to sustainable management of river resources is identified. Table 1 provides an overview of the information utilized to examine the basin characteristics, and geomorphic parameters relevant to the study.

Table 1: Data, sources, and methods of Analysis

Data/parameter	Sources	Methods
Geological map/ geology	DMG,1994	Image interpretation
Drainage Characteristics/ network	30 m DEM, SRTM 2020	Using ArcGIS
Hydro-metrological/ rainfall	DHM (2015-2021)	Excel, Graph
Land use map/ land cover	ICIMODE (2020)	Image Overlay (ArcGIS)
Sediment Grading/ variation	Field and Lab 2022	Sieve analysis
Sediment load/ concentration	sample data	Lab test
River Morphology	Google earth/field visit 2022	Time series images

3.2 Sampling Design

The chainage interval and location of the sediment, water sample, and river morphology changes study were chosen using a non-probability sample design, such as the judgemental/purposive/expert. The samples have been chosen and gathered through a casual talk with an experienced specialist. Figure 2 below displays the sampling sites, study zones, and landslide locations.

Figure 2: Sampling Location Map (Google earth-2022/06)

4. Basin Characteristics

4.1 Geology

With the creation of the Nawakot Complex, the Shardu basin has evolved in a significant portion of Nepal's midland. Between the Lower Nawakot Group and the Siwalik Group is the Main Boundary Thrust (MBT). It is composed of metaclastic sediment, quartzite, phyllite, slate, dolomite, limestone, and nonclastic sediments such as metasandstone and slate [8]. It belongs to the Lesser Himalayan tectonic unit. Although this group is at least 6 km thick, its base is not visible. Five formations make up the lower Nawakot Group: Dhading Dolomite, Nourpul Formation, Dandagaon Phyllite, Fagfog Quartzite, and Kuncha Formation. The materials that make up the upper Nawakot group are slate, dolomite, limestone, phyllite, and quartzite. the basin's geological division, as displayed in Table 2. Lesser Himalayan Group's total area is 14.07 km2 or 56.45% of the total area. The foreland basin deposit contains the Siwalik, Sub-Himalaya, or Churiya groups, which make up the middle zone of the basin. The zone is made up of fluvial material from the Neogene to the Quaternary that formed Nepal's southernmost hills range [9]. The MBT and MFT both encircle their northern and lower halves, respectively. It is located in the Shardu basin and spans a distance of 5 to 6 km. It comprises the Lower, Middle, and Upper Siwalik lithology. Fine-grained, hard, red, ash grey and reddish brown sandstone dominate this zone basin. Conglomerates, sandstone, siltstone, and some clay are the rock types that best represent the upper Siwalik. This zone, which made up 41.82 % of the entire basin, was a major supplier of sediment. River deposits mostly developed in the lowermost portion of the basin, the Gangetic Plain. A total of 1.74% of the land is covered by the Gangetic Plain. The Main Frontal Thrust (MFT) in the south separates the Siwalik from alluvial deposits in the Terai plain. Where the alluvium in the piedmont zone is located on the frontal fault, it is most active [8]. The Gangetic Plain's river also known as Terai is extremely sensitive to unstable morphology. Braided channels are frequently encountered because of the abundant sediment supply from the upper zone. Figure 3 below depicts the geological segmentation of a basin.

Table 2: Geological coverage of basin.

S.N.	Geological division	Area (Km2)	Area%
1	Lesser Himalaya	14.07	56.45
2	Siwalik group	10.423	41.82
3	Gangatic Plane	0.433	1.74

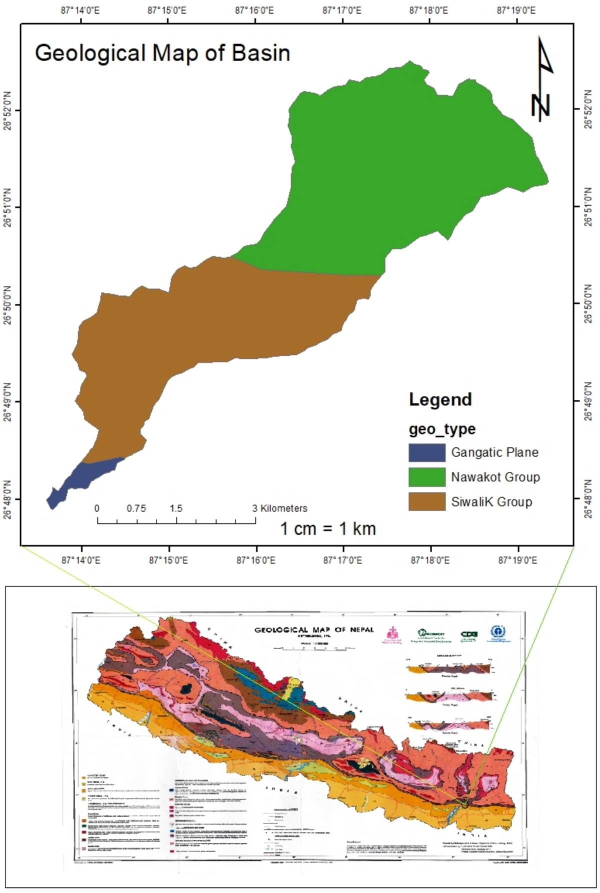

Figure 3: Geological Map of Basin (Department of Geology and Mines-1994)

4.2 Drainage Network and Channel Characteristics

The downstream characteristics of the river morphology in the alluvial plain region are mostly controlled by the drainage network and channel characteristics of the hills catchment.

Table 3: Drainage network characteristics of Basin

Stream order(u)	Number of Stream (Nu)	Total Length (Lu)
1	31	18.91
2	14	9.39
3	11	8.46
4	5	3.10
Basin	61	39.88
	Drainage density	1.6

The drainage density for the entire basin is 1.6 km/km2. Because of the small basin's drainage density, which is considerable, the terrain is rough and has a significant potential for erosion.

The average slope of the basin was 0.4364 (23.58°), which is considerable considering it is in the Siwalik Zone. Considering the stream order classification scheme [10], the number of order and the bifurcation ratio is presented in Table 3. The basin has 61 streams totaling 39.88 km in length, including 4 order streams (figure 4). The smaller Himalayan range has an average stream segment with a greater slope, which significantly increases the stream gradient. Additionally, they have a capacity that is big enough to carry large amounts of silt, particularly monsoon-related massive debris flows.

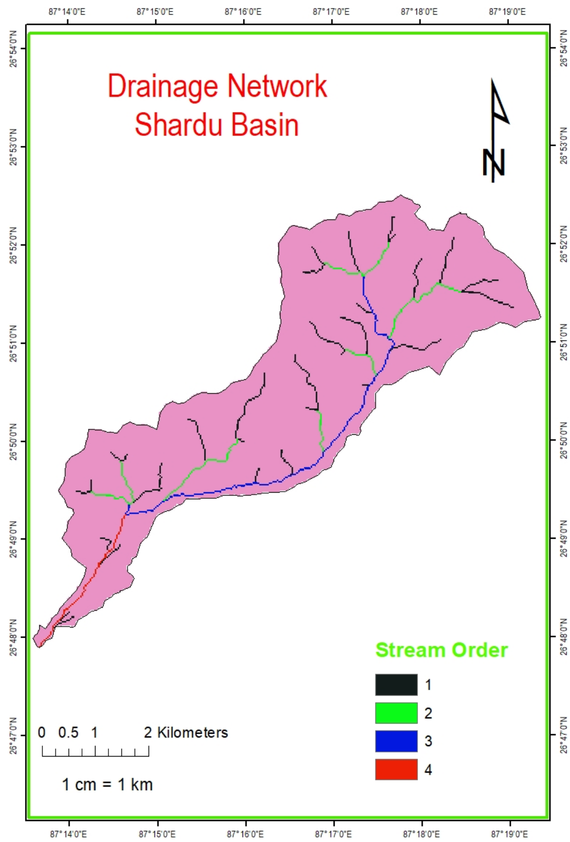

Figure 4: Drainage network of Basin.

4.3 Rainfall

There are no stations for recording rainfall or temperature in the Shardu River basin. The closest weather station is 6 Km away from the exit of the basin, in Dharan. The Department of Hydrology and Meteorology of Nepal oversees and runs the station. Station ID 1311 is used to analyze the climate characteristic. The station is situated at latitude 26.79 and longitude 87.29, with an elevation of 310 masl. The monthly and mean yearly rainfall are depicted in Figures 5 and 6, respectively. About 2150 mm of rain falls on average each year. July is the wettest month in the Shardu basin, followed by August, September, and June. The maximum rainfall between 2015 and 2021 was found to occur in 2020. Nearly 80/100 of the yearly rainfall was produced by the monsoon in its entirety from June to September. The Number is extremely vulnerable to floods, erosion, landslides, and other water-related disasters during this time. The largest temperature variation from 2015 to 2021 is 34.32°C in April to 9.99°C in January, according to the temperature data.

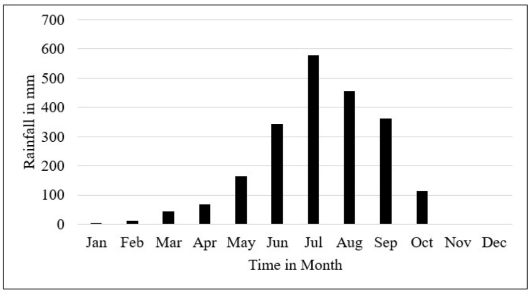

Figure 5: Average monthly rainfall in mm (2015-2021)

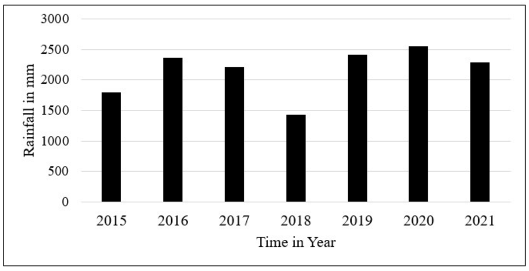

Figure 6: Average annual rainfall in mm (2015 to 2021)

Flood Analysis

Since there are no long-term discharge records for rivers, estimating the flood flow using empirical approaches is sought. The empirical techniques are based on the catchment's extent, slope, elevation below 3000 m, wetness monsoon index, etc. Several empirical apexes were used to calculate flood discharge for the Shardu basin. The flood discharge calculated using Modified Dicken's Methods appears to be the most accurate. As a result, the researcher employed flood discharge for various river analyses using modified Dickens' methodology. The basin has been split into upstream and downstream river sections for precise analysis. The basin area of the river reach upstream is 11.47 km2, and the outlet area is 24.925 km2. 54 m3/s was discovered to be the outflow discharge of the basin for a 50-year return period.

4.4 Landuse Pattern

The data obtained by ICIMOD were used to create the study area's land use map. Data for the year 2020 was downloaded. The majority of the area is used for trees, then for crops. It was noted that there was a lot of arid area in the upper portion of the basin. The Shardu basin had also been covered with built-up areas and permanent water bodies. More than 88/100 of the total area of the catchment is used for land uses other than agriculture, including forest, shrubs, and grass (table 4).

Table 4: Land Cover of the Basin.

S.N.	Land cover	Area (%)
1	Tree Cover	86.86
2	Shrub Land	0.06
3	Grass Land	0.96
4	Crop Land	3.05
5	Build up	1.98
6	Barren	2.34
7	Permanent Water Bodies	4.75
	Total	100

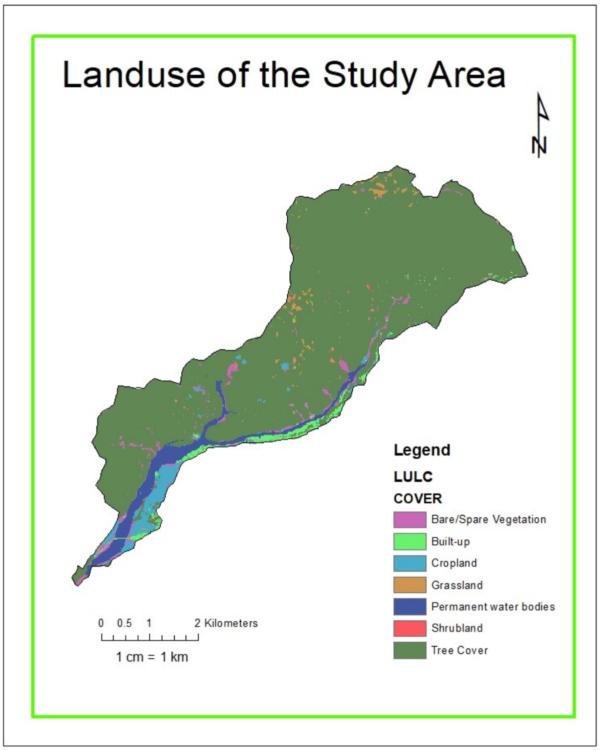

Figure 7: Land Use Map of the Basin (Source: ICIMOD, 2020)

The flood plain zone, which is located south of the Piedmont belt "bhabar," is where most of the agricultural and urbanized land in the Shardu basin is located. The area south of the Siwalik Hills is known as Bhabar. The Indo-Gangetic Plain's northern boundary is where the material from the Siwalik alluvial base spilled down from there. In the Shardu Basin, there is some grassland present along the bank corridor but no forest. Therefore, land loss and damage to the river control structure are potential consequences of bank erosion in the upper watershed and flood with deposition risk. The results of the basin's land cover are displayed in Figure 7.

4.5 Sediment Characteristics

4.5.1 Sieve Analysis

The context for sediment movement and sedimentation in an alluvial river is the morphology of the river's channel. The capacity of a river to carry sediment is influenced by several variables, including slope, flood discharge, sediment gradation, and the average size of the material to be transported. The grain size analysis test is used to calculate the proportion of each grain size that is present in the sample, and the test's results can be used to create a grain size distribution curve. A sieve analysis (particles larger than 0.075 mm) and hydrometer analysis are the two basic techniques for determining grain size distribution (particles less than 0.075mm). In this study, the silt was graded using the sieve analysis method. The diagram above divided the study basin into various sections, and samples were taken at ten distinct river channel locations. The direct sampling technique was adopted to sample the silt in the river bed. The Purwanchal Engineering Campus at Dharan's civil engineering lab performed the sieve analysis. Under the supervision of a researcher, the sieve analysis was done. For this analysis, IS standard sieves of the following sizes were used: 40mm, 26.5mm, 20mm, 16mm, 12.5mm, 10mm, 4.75mm, 2.36mm, 1.18mm, 0.6mm, 0.3mm, 0.15mm, and 0.075mm. The details of the outcomes of the analyses at numerous places are presented in Figures 8, 9, 10, 11, 12 & 13 below shows the outcomes of the sieve analysis.

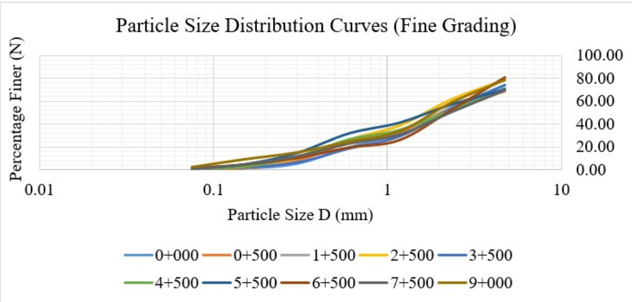

Figure 8: Particel size distribution curve (Fine Grading)

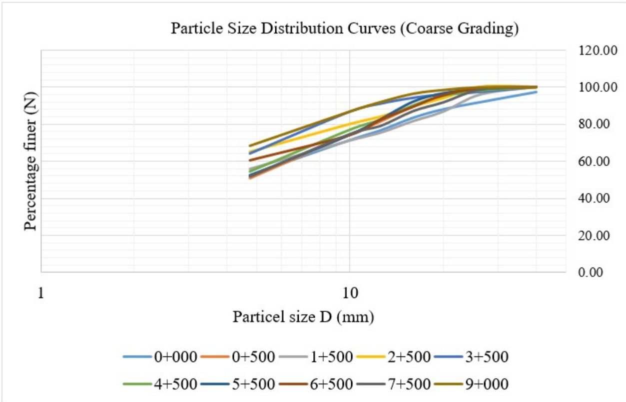

Figure 9: Particle size distribution curve (Coarse Grading).

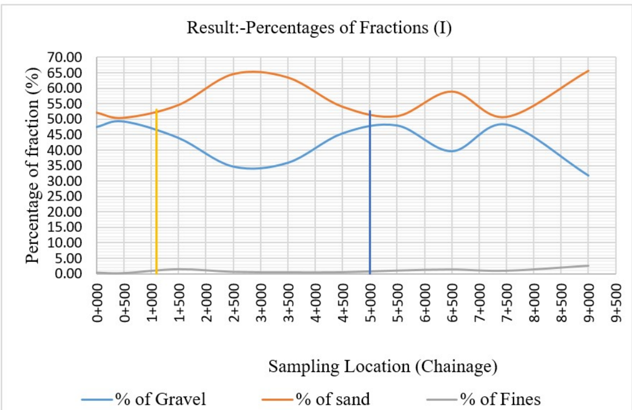

Figure 10: Different fraction of Sediment.

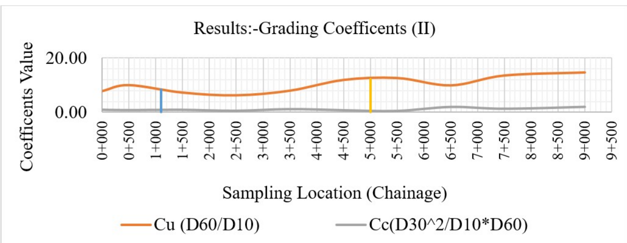

Figure 11: Grading coefficient of sediment

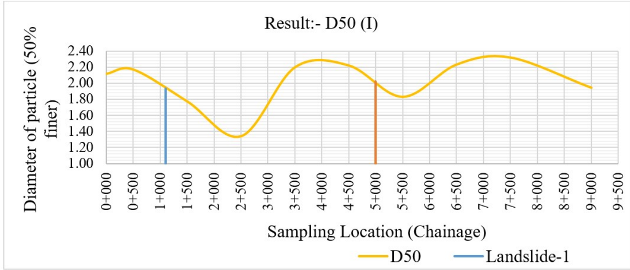

Figure 12: Mean size particle of sediment.

Results: The findings demonstrated that as one moved from the top reach (Siwalik Zone) to the lower reaches of the basin (Gangatic Zone), the percentage of gravel decreased while the percentage of sand increased (figure 10). Figures 8 and 9 above depict the river's fine and coarse grading variations. At locations 0+000 and 9+000, the proportion of gravel was 47.40 % and 31.48 %, respectively. Upstream to downstream, the percentage of sand changed from 52.14 percent to 65.67 percent. From upstream to downstream of river reaches, the percentage of fines rises. As one moved from upstream to downstream, the uniformity coefficient's value increased (figure 11). From upstream to downstream, the sediment's coefficient of curvature increased (Figure 11). At locations 0+000 and 9+000, sediment's mean size (D50) decreased from 2.11 to 1.94. (figure 12). The overall findings revealed that all parameters computed in the results change after the first and second large landslides. There is a greater variation after the first landslide than after the second. At location 3+500 and after location 6+500 to 9+000, the curvature coefficient value is greater than 1. There was evidence of well-graded material at locations 3+500 and after spot 6+500.

4.5.2 Sediment Concentration

A river water sample was used to determine the sediment concentration in the flowing water. The various sites were picked for two distinct scenarios: under normal flow conditions and during a period of floods. In the Purwanchal Engineering Campus chemical lab, the sample's concentration was ascertained after it was collected. Evaporation was one of the procedures used to determine concentration.

Table 5: Sediment Concentration of River flow.

Description	Location	Concn.(ppm)
Sample-1	0+000	50
Sample-2	4+500	240
Sample-3	7+500	310
Sample-4 (Flood)	7+500	3120

The findings demonstrated that sediment concentration increased from upstream to downstream and was 10 times higher during periods of flooding in the same region. According to the concentration measurements, basin erosion increases from upstream to downstream. The value of the sediment during the period of floods indicates the possible duration of the basin's soil loss. The outcomes of the water's sediment concentration are shown in Table 5 above.

5. Planform and Cross-Sectional Change in River Morphology

The erosion (Bank and upstream of the basin), depositional, and channel abandonment between 2009 and 2022 channel planforms are evidence of the changes in river morphology that have taken place. These findings are based on Google Earth imagery and field observations. For this study, all river reaches were separated into three zones Zone-1, Zone-2, and Zone-3, as shown in the picture(figure 2). The river channel was bigger in 2009 than it would be in 2022. Due to the development and implementation of river control projects, the Shardu River's area of river reaches is steadily decreasing. The three zones in this study's river reach correspond to Zone-1 as the Siwalik group, Zone-2 as the transition group, and Zone-3 as the current formation group. Zone-1 locations are more vulnerable to erosion because of steeper gradients, whereas zone-2, often known as a foothill, is equally vulnerable to deposition. In all river reaches, the area recovered by aggradation exceeds the area lost through erosion, which is a sign of an excessive sediment load from the upper reaches. 41.21 acres of land were recovered from 2009 to 2022. Table 6 contains the area change calculations for the various zones. Zone-1 and Zone-3 morphology changes more linearly than the intermediate zone-2, according to the results of the channel investigation (figure 14). Zone-1, Zone-2, and Zone-3 all had area decreases, with 31.68 %, 54.27 %, and 20 %, respectively. The Siwalik portion of the catchment has a higher density of channel networks in the basin, which moves more material to the lower catchment. The cross-sectional change at several locations was investigated. The studied cross-sections exhibit both degradations in the upper zone in the form of bank and bed scouring and aggravation in the form of deposition at the bed or bank. This shows that morphology is quite dynamic because rivers constantly alter their plan and cross-sectional appearance. Large sediment discharge from rivers and a decrease in flow depth as they go downstream are two further indicators of the depositional morphology of river beds and cross sections (figure 14). The change in the river morphology causes lateral erosion and avulsion in the upper zone, river shift, widening bends, and bed sedimentation. The morphology and processes of the river have been impacted by the construction of spurs and embankments to address bank erosion and flooding control issues on either bank of the river.

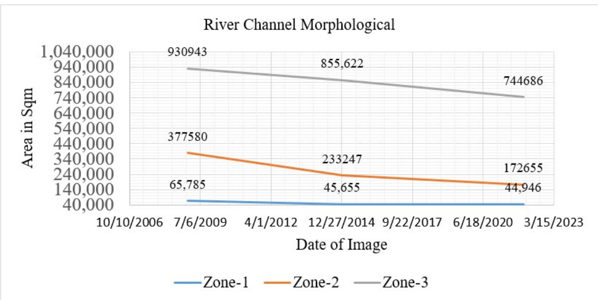

Figure 13: River Channel Morphology Changes.

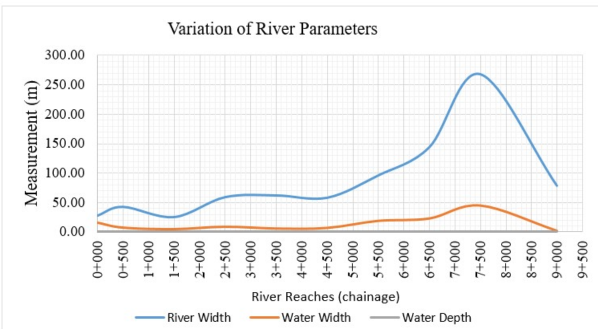

Figure 14: River and Flow parameters changes.

6. Conclusion and Recommendation

The Siwalik group, which makes up much of the basin's northern portion, is made up of a wide variety of geological formations, while the Plain Terai, which makes up much of its southern portion, is relatively recent. The catchment consists of a drainage pattern controlled by structure, a drainage network of the fourth order stream with a drainage density of 1.6 km/km2, and the Shardu river basin is susceptible to soil erosion and natural hazards like floods and landslides due to heavy rainfall during May to August. Sediment concentration imbalance during flooding and normal flow reflect heavy erosion in the upper basin. Due to the diverse geology and basin characteristics, the average sediment-grading output of the basin was found to be significantly varied. The sediment grading curve demonstrates that the material in zone 1 was discovered to be less accurately graded than that in zones 2 and 3. Zones 2 and 3 are therefore more suited for material extraction. The major landslide presence in the basin influences the sediment grading and hence river morphology of the basin. At the lower zone, both the sand percent and the sediment quantity increase. As the Planforms of zone-3 remain stable while susceptibility to erosion in the upper zone increase. River parameters such as river width and water flow width increase from upper reaches to lower reaches which reflect the braided nature of river morphology. The river management plan affects bye risk of flooding and deposition due to excessive sediment imbalance at the lower zone. The river morphology pattern reveals that erosion is significant in the upper catchment in the Shardu basin, indicating that it can be utilized as a natural resource for many purposes as well reflect the demand of watershed management. Special multi-dimensional geomorphic such as erosion and deposition should consider for river management infrastructure for the sustainable management of rivers in the cure region. As a result, a river system conservation program that reveals scientific practices and management of river morphology is needed.

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