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Morphological characteristics and changes in the Upper Reach Gumara River in Ethiopia from 1957 to 2020

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A B S R A C T

Human intervention with the natural landscape, including various river systems, is increasing in most parts of our country due to population growth and their infinite demand. As a result of this, the river system was jeopardized, causing irreversible damage to the socioeconomic and infrastructural systems. Morphological characterization and change evaluation of rivers are essential prerequisites for investigating their historical evolution and making reasonable estimates about how rivers might adapt to changing natural conditions and increasing anthropogenic impacts. This study focuses on the upper reach of the Gumara River along a 47.336 km stretch because it is a highly meandering and dynamic fluvial system with minor natural and anthropogenic influences that harm living and nonliving things around the flow path. We use satellite images as a data source, and the study reach was divided into six sections based on the waterway geometry and various forms of human intervention along the river, for detailed river morphological characterization and change detection, and to know the disturbance that facilitates the change in sub reach. In addition to satellite imagery, field observations, informal interviews with local indigenous people, laboratory analysis of bank material, and Meteorological and Hydrological data were used. The primary goal of this study was to assess the Morphological Characteristics and Change of the Upper Reach Gumara River over a 64-year period in Tana Basin, Ethiopia. Image analysis software (ERDAS Imagine 2015 and Arc GIS 10.5) was used for data preparation and analysis, and to characterize and detect the change of study reach, various morphometric parameters such as Sinuosity index, braided index, River center line, actual River length, river width, meander neck length, and River area were determined. From the entire period of 64 years of sinuosity index analysis, the sinuosity was increased by 5.49%. The section between five and six had a 63% reduction in neck length. Over a 64-year period, the overall width increased by 0.348 m per year. All of the morphometric parameter results and social information show that the upper reach of the Gumara River was dynamically changed and disrupted the surrounding socioeconomic system, implying that critical measurements should be designed and implemented.

Key words: Morphological characteristics - Neck length- Upper reach Gumar- Antropogenic and natural impact

1.0. INTRODUCTION

Rivers are a crucial aspect of the earth's biological, hydrological, and physical systems, as well as providing a variety of services to humans. Despite our reliance on rivers, human activities, notably growing strain on water supplies, have resulted in a global degradation of river health. Many river systems' long-term survival is dependent on successful management, and one major component of river management is to organize streams into natural or contrived groups based on common traits (Keast, 2014). This classification can help with river management by boosting awareness of river form and process within the general complexity of rivers and River classification has been critical in creating knowledge of the relationships between hydrology; geomorphology, and ecology and also, knowledge from a specific river type at one location can be extended to other areas of the same type, lowering resource requirements (Keast, 2014). River physical features have changed significantly, owing primarily to human effects and morphological changes of the river fundamentally cause river management issues, so understanding the spatial and temporal change of river morphology is important for river users, especially if the river is subjected to multiple uses (Török & Baranya, 2017)**.** Various works of literature educated us River morphology has been a significant challenge to scientists and engineers who recognize that any endeavor involving river engineering must be founded on a detailed understanding of the morphological elements involved as well as the responses to imposed change. This is because physical changes in the natural river system might result in a longitudinal erosion-to-deposition pattern that can lead to the destruction of diverse socioeconomic systems (Guo et al., 2021). Characterizing river passages from a hydro-morphological perspective is a vital requirement for analyzing their past evolution and making realistic predictions about how rivers may adapt to changing climatic circumstances and rising human activities (Ulloa et al., 2018). River morphology is an important route for human understanding of river geomorphology and geographical information transmission, and continuously updated river monitoring data and products provide enormous opportunities for explicit expression of river physical features and associated processes in an ever-changing environment (Li et al., 2022). Most rivers around the world have numerous negative effects on the environmental system in addition to their benefits from natural disasters such as floods. Such natural disasters are exacerbated when rivers are disrupted by anthropogenic activities that alter their shape and planform. Thus, river studies in terms of hydraulic characteristics, sediment, anthropogenic activity, morphology, and planform are critical for conserving natural resources and society (Sapkale et al., 2016). A river or stream is dynamic over time, and the meandering process is the most important morphological property of a river, which is dominated and governed by hydraulic, hydrologic, and topographic characteristics of the river and its drainage area. When moving water in a stream erodes the outer banks and widens the valley, a meander forms, posing a civil engineering problem for local municipalities struggling to maintain stable roads and bridges(Deb et al., 2012). Despite numerous studies conducted in the Lake Tana Basin, the effects of development activities and other natural and man-made incidents on the upper reach of the Gumara River and its tributaries have yet to be addressed. Abate et al (2015) Despite the lack of assessment of the upper reach of the Gumara River, the lower reach has been highlighted. The study here is evaluating the status of the upper Gumara River from Bahir Dar to Gonder Asphalt Road up to the confluence point of Licha Gumara and Sendega Gumara (Sebat Wedel Gumara), locally known as Aba Gunda. The river is so mender and influenced the surrounding village, infrastructure, and agricultural land between the Bahir Dar to Gonder asphalt Road and Aba Gunda, but the river changes and its effect, including the drivers of such changes, in this section were not thoroughly investigated and documented prior to this study. Thus, reason and the like initiated a study on this section and Such research assists us in investigating and comprehending the existing problem, as well as distinguishing whether the planform change drivers are primarily human or natural in nature. This allows us to plan for long-term, low-cost catchment management and river restoration practices. ank erosion is a major geomorphologic process in alluvial floodplains that can be caused by both natural and anthropogenic factors. Bank erosion is extensive in various research areas, and the roots process of soil and land-use changes; as a result, such research was important for water and land management, as well as the protection of concentrated bank erosion (Dragicevic et al., 2011). Furthermore, in the upper reach of the Gumara River, lateral movement of the river bank is a major problem, and a large amount of soil was lost from the bank in addition to soil loss from the watershed, which increased the lake level over time, necessitating serious studies to address the problem and design strategies to reduce the risk. River bank erosion causes changes in the position of bank lines as well as other changes within the channel (Sree et al., 2014) and it has a significant socioeconomic impact, including effects on livelihood, agriculture, the environment, and other sectors, making such studies extremely valuable for accountable bodies (Islam et al., 2017). Understanding the morphology and behavior of the river is required for a scientific and rational approach to detecting different river problems and proper planning and design of water resources projects, and thus morphological studies play an important role in planning, designing, and maintaining river engineering structures (Sree et al., 2014). Rivers are shaped by the sediment loads they carry, the variability of the river's flow, the types of rainfall, catchment land use land cover changes, population settlement, manmade infrastructures, the cohesion of the material in their banks, the slopes they flow down, and the rocks they cut into (Ibisate et al., 2011). Channel dynamics are an important component in the evolution of vast alluvial floodplains, as well as the disturbance regime that is essential for floodplain patterns, and knowledge of river forms, energetics, and so on is important for understanding or can assist land and natural resource managers in taking necessary measures to minimize injury (Akana & Akpofure, 2019). Large alluvial rivers, in particular, are complex and highly dynamic geomorphological systems with enormous cultural, socioeconomic, and political value (Harmar et al., 2005). Planform dynamics of these alluvial rivers are a complicated process and vary from one system to another and it was analyzed using various parameters including channel length, width and radius of curvature and actively meandering river adjust their planforms according to spatial and temporal variation of numerous drivers including discharge, sediment load, channel morphology, and bank materials properties (Harmar & Clifford, 2006). Prior to this study, various studies on the upper Blue Nile basin, particularly the Gumara watershed and the river itself, were conducted, and the various issues were addressed using a variety of approaches. Gashaw and Legesse (2011) investigated flood hazard and risk assessment in Fogera woreda using the Ribb-Gumara catchment. For the assessment of flood hazard and related risk in the flood plain, modern GIS and remote sensing techniques were used, and the main finding of the work indicates that most of the Peasant Associations (PAs) in the downstream part of the catchment, as well as the various land uses in that area, were within high to very high flood hazard and risk levels. Wubie et al (2016) Patterns, causes, and consequences of land use/cover dynamics in the Gumara watershed of Lake Tana basin were studied over 48 years using two sets of aerial photographs (1957 and 1985) and a multispectral Spot5 image (2005) in a GIS environment. Socioeconomic surveys, focus groups, and field observations were conducted. The study's findings revealed that cultivated and settlement land increased by 21.99 percent, while forest land, shrub land, grass land, and wetland decreased by 85.30 percent, 91.39 percent, 76.15 percent, and 72.54 percent, respectively, over the analysis period. Abate et al. (2015) assessed Morphological changes of the Gumara River channel over 50 years, upper Blue Nile basin, Ethiopia, on the lower reach of the Gumara river. The study focused on a 38-kilometer stretch of the Gumara River over a 50-year period, and it revealed that agriculture development was accelerating in the catchment and that flooding of the alluvial plain had become more common in recent years. The study's main goals were to document changes in the Gumara River's channel planform and cross-section and to investigate whether the changes contributed to the frequent flooding or vice versa. The primary goal of the research was to determine the channel planform and bed morphology (vertical changes) for the time period of (1957-2006), and the findings showed that the lower reach of Gumara near its mouth has undergone significant planform changes.

2.0. Materials and Methods

2.1. Descriptions of Study Area

The Gumara River feeds into Lake Tana at 11°53′N 37°31′E from the East hot spring on the Gumara's bank at Wanzaye, which was popular in therapeutic hot from the late 18th century to the present. Mount Guna, the highest mountain in the south Gonder zone with an elevation of roughly 4120 meters above sea level and located near the cities of Nefas Meucha and Debre Tabour in Ethiopia's northern Amhara region, is the source of this river. This river is part of the Lake Tana basin, which is situated between Wereta and Hamusite on Lake Tana's northeastern side. Dera, Farta, Fogera, and a piece of Estie Weredas are all drained by it. Mountains, very rough and fragmented topography with steep slopes characterize the river, which is drained to the plain in a westward direction due to variations in the valley floor with flat to mild slopes, and the river overflows its bank during the wet season. The river's economic worth is crucial for alleviating food scarcity in both neighboring societies and at the national level, and it is also used as a supply of sand to meet the sand requirements of nearby construction sites, as well as providing job possibilities for the river's unemployed young. The study site is situated between Bahir Dar's main asphalt road and the confluence point of two streams, Licha Gumara and Sebat Wedel Gumara (Fuafuat Gumara and Sendega Gumara), with a total length of 47.336 kilometers. Another gravel road connects Debre Tabor, Licha, Estie, Arb Gebeya, Anbesame, Wanzaye, and Guranb, providing access to the area. The study location covered an area of 1383.6162 square kilometers.

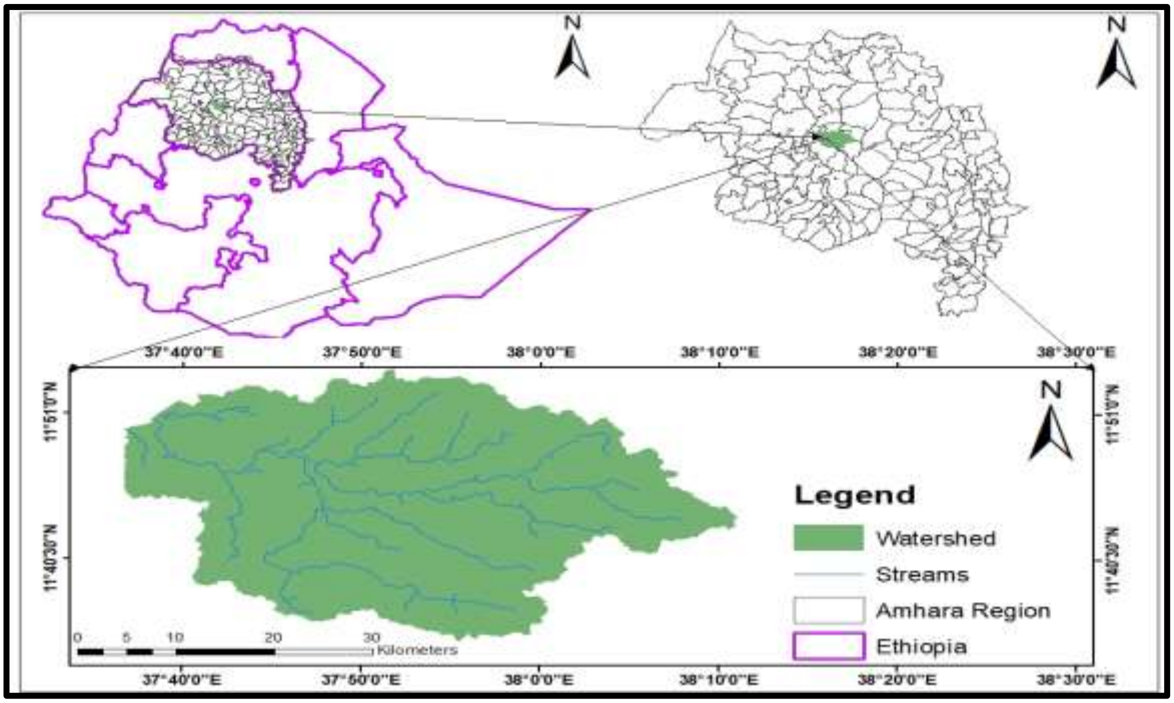

Fig1.Map of the study Area

2. 2. Data sources and data processing methods

Aerial photograph of 1957 (5 m by 5 m size), gathered by the Ethiopian Map Authority (EMA) and got from Bahir dar university, Ethiopia, land sat images of 2013 (15 m by 15 m) and 1999 (30 m by 30 m size), and sentinel-2 image of 2020 (10 m by 10 m size) obtained from the web-site www.glovis.USGS.gov. Spot images from 2006 (5 m by 5 m) and 2013 (2.5 m by 2.5 m) acquired in January from the NABU project purchased for the Lake Tana area Biosphere reserve study and taken from Amhara design, supervision, and work enterprise, as well as Google earth images from 2006, 2013, and 2020. The braided index of the study reach was calculated using Google earth image from 2006, 2013, and 2020. In addition to the various images gathered from various site filed observation and data collection, including various anthropogenic activities (sand mining, farming practices, and infrastructure building) around the study reach, the current bank erosion and deposition at different sections and the ground cover were observed to interpret and prove the result from the image, and laboratory analysis was conducted to determine the river bank material grain size. Interviews were also conducted with local indigenous people about the case of the river overtopping, bank collapse, and type of watershed management used in previous years. The water well built around the study reach in 1977 Fig (1b) was also used to demonstrate the reality of river bank retreat. Rainfall, streamflow, watershed soil type, and sediment data were collected from the West Amhara National meteorological service agency and the Amhara Design, Supervision, and Work Enterprise. We perceive the case of the river overtopping, bank crumbling, and type of watershed management undertaken in prior years based on local interviews. To avoid overestimating or underestimating the river's plan form change, a time series of dry season satellite images from 1957 to 2020 was used to visualize the temporal change in plan form dynamics. Using several morphometric metrics such as

2.3. Generating and analyzing images

Because any image received from any source is unusable unless it has been pre-processed, image pre-processing is a technique for repairing distorted images before they are utilized for further processing. Aerial photos must first be scanned before orthorectification may be conducted in order to extract various morphometric parameters. The aerial image has already been scanned, orthorectified, and mosaicked in this work, therefore only geometric correction was done with spot image 2013. In the first step of image processing, the layer stack was processed with ERDAS Imagine 2015 software, followed by radiometric correction to reduce atmospheric effect and geometric

(sinuosity index, braided index, river width, steam length, River center line, planimetric Area, and bank line, which were retrieved from numerous historical images using GIS10.5, the change and trend of channel migration was recognized all around.

correction to rectify geometric distortion of the image. Then, using ArcGIS 10.5, on-screen manual digitization for different features of the river, such as Riverbank line and bars, the river midline was determined from the digitized river bank, and this line was then split into six different sections Fig (2), This enables the simple calculation of various morphometric indices as well as detailed information about the study's reach. The layer stack was processed with ERDAS Imagine 2015 software in the initial step of image processing, followed by radiometric correction to lessen atmospheric effect and geometric correction to correct geometric distortion of the image.

Fig 2. Damaged Water Well Due To Lateral Movement Of River Bank

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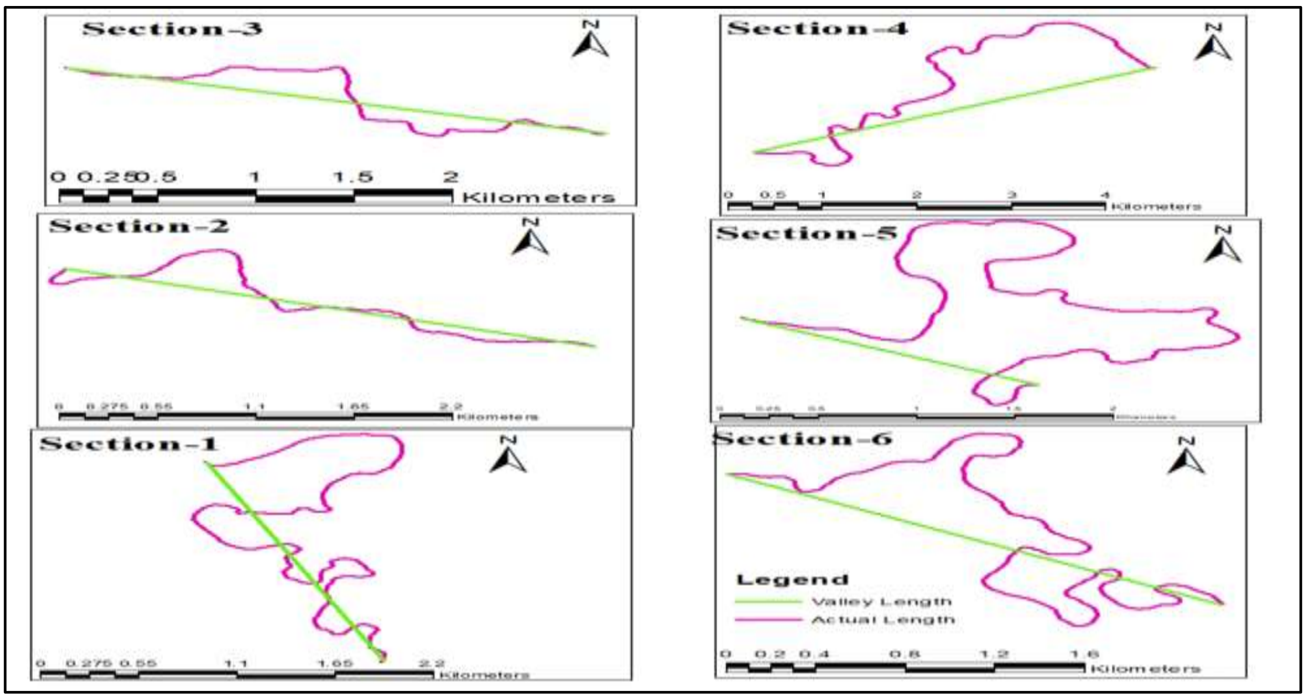


Fig 3.Different section of the study reaches and ways of measuring valley length

2.4. Data analysis and change detectionmethods

The creation of aerial photography and other satellite images using GIS and ERDAS Imagine was the pre-request to analyze, edit, and interpret the results. This allows us to measure stream length, valley length, sinuosity index, braided index, river width, river area, and neck length, among other morphometric characteristics. In addition to the satellite image data, hydrological data such as rainfall, flow, and sediment data were evaluated using graphs and tables, making it easy to see how they change over time. Gap filling, data reliability checks, and outlier testing were all performed before using rainfall data. Long year average methods were used to bridge the gap between the two data series.

2.4.1. Rainfall, streamflow, and sediment analysis

a) Checking the Reliability of Rainfall Distribution

The quality and completeness of data determine the outcome of data analysis. Lack of good quality rainfall data will have a negative impact on the analysis process, resulting in skewed analysis results. As a result, accurate water resource planning and management is dependent on the presence of consistent and precise precipitation data in meteorology stations (Le, 2020) . It should be checked for data consistency and appropriateness before using rain fall data. The data series is consistent and appropriate if the relative standard error (σ) is less than 10%, (Tesfa Gebrie & Ademe, 2012) ,(Cookson & Stirk, 2019) and (Sileshi, 2015),(RAES, 2013).

Test for outliers; Outliers are data points that deviate from the overall trend of the data. Outliers can thus have a major impact on the magnitude of a data series. Rainfall plays a role in influencing the natural river system in the case of river change; hence a critical rainfall analysis should be conducted. The relative stand error and outlier test were employed in this study to examine the reliability and appropriateness of the recorded data for the study region, and the analysis result indicated that the standard error of the mean (Se) was 10.3% and relative standard error was 2.3%, which is less than 10%. As a result, the 63-year data was accurate and dependable.

Outlier test result; To test outliers, first estimate the skewness coefficient (Cs), which should be more than 0.4. As a result, Cs was calculated to be 0.7, which is higher than 0.4. As a result, upper and lower outlier tests should be carried out. The value for the height outlier test was 741. 3 mm. The recoded highest rain fall value is (670.6 mm), which is lower than the higher outlier (741.3 mm). As a result, there is no higher outlier. The lower outlier test value was 281.29 mm, as well. However, with the available data, the lowest recorded value was (313.4 mm), which is higher than the lower outlier value (281.29 mm). As a result, there is no lower outlier. As a result, the recorded data for both upper and lower outliers is consistent, and it can be used for further analysis in a discreet manner. The available rainfall data for my study ranged from 1957 to 2019, and its impact on planform dynamics was determined by visualizing the trend line distribution as shown in Figure (4).

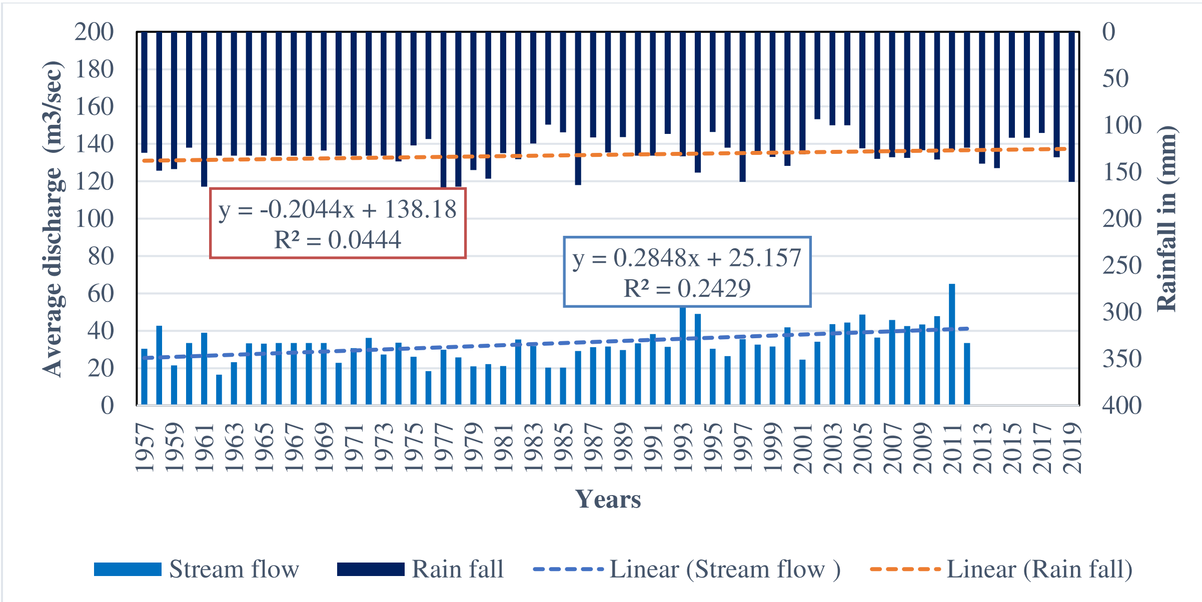


Fig 4.Annual rain fall and stream flow distribution

b) Flow and sediment concentration in a stream

Advanced Streamflow is a key driver of hydraulic geometry alteration in most natural river systems. Increased river discharge in the natural river system helped scouring of the riverbed in the river channel, resulting in spatially undamaged bank erosion and channel retreat. A trend line of stream flow distribution Fig (3) was used in this study, which looked at 56 years of data from 1960 to 2015, to see the spreading and its effect on river platform dynamics. The river is significantly impacted by silt movement (Zhang et al., 2014). The sediment movement mechanism has the capacity to change the riverbed's morphology (Gharbi et al., 2016). And the two most significant aspects in river development and management are erosion and deposition. Because of the high flow reported during floods, erosion occurs more frequently during these times, resulting in changes in river morphology (Gharbi et al., 2016).

2.5. Morphological characterization and digitization

Digitization is done with GIS 10.5 to create a map that is editable by nature, and it usually results in vector data sets, which can then be translated into a user-friendly format. Starting from Bahir Dar to Gonder asphalt road and following the main study reach up to the Confluence point of Sendega Gumara and Licha Gumara for the nominated study years (1957, 1999, 2006, 2013, and 2020), bank line digitization in both right and left directions was conducted for the nominated study years (1957, 1999, 2006, 2013, and 2020). The length of the stream and the length of the valley were then measured to compare the length of the stream and valley for each study year and to determine sinuosity for each part of the study reach. Sinuosity is the only plan-form feature included in the first delineation of stream types, and it depicts how the stream has changed its slope. It is quantified as the ratio of stream length to valley length, whereas Braiding index is 2 times the total bar length divided by the reach length (Brice, 1964) . The distance between two banks, as drawn from images, is used to determine the river's width. The width of the river is calculated using the image, taking into account the point bars and active corridors, which are submerged during the summer. Active channel width and total channel width are two measurement methods that can be used to measure the change in river width. The width of an active waterway includes the width without vegetation, medial point bars, and islands (Esfandiary & Rahimi, 2019). Total channel width was used in this study because total river width comprises the river, as well as bars and medial islands, and was calculated by subtracting total channel width variations during the specified time span. Transect methods were used to measure width, with a 250 m gap between transects. This means that four measurements per one kilometer were taken to see the change in river width over time and space, i.e., 48 cross-sections in section one, 16 cross-sections in section two, 20 cross-sections in section three, 32 cross-sections in sections four and five, and 24 cross-sections in section six, for a total of 172 cross-sections for the study years (2006, 2013, and 2020) using Arc GIS 10.5 for each. After measuring the width to determine where the river narrows or widens, a subtraction was done between two-time series data, namely the width of the river at time (1) and the width of the river at time (2). The bar status was scanned from Google earth images of 10/12006, 9/12013, and 13/12020, and then saved as a kml format image, which was then converted to a layer and projected to compute the area of the bar for each year using GIS 10.5. Finally, a comparison was conducted between the two images (2006-2013, 2013-2020 and 2006-2020). To determine the length of the neck in the study, a total of four severe bends was chosen to examine how the bending of each region of the study reach varied over time. Parts 1,5 and 6 of the study were chosen among the six sections since this portion had an excessive bend in comparison to the others. Section six had three different bending points, section one and five had only one bending per section, and section 5&6 had only one bending, and then by fixing the common point for measurement of bend migration for each study year, measurement was conducted using measurement tools in Arc GIS 10.5, and to observe the occurrence of the change subtraction were made for each consecutive study year, i.e., 1957-1999, 1999-2006, 2006-2013, and 2013-2020. For land use and land cover classification, a supervised classification strategy using maximum likelihood classification methods was applied with a land sat image from 2013 and a sentinel image from 2020. This classification was based on the research area's prior pattern recognition knowledge. To process the main classification, the supervised classification involves several steps, including manual identification of the place of interest as a reference inside the image. Only significant land use land cover types were considered for classifying the LULC using the above technique, due to the fact that the change in land use land cover types is unpredictable. As a result, there were five major land use land cover classifications in this study including agricultural, settlement, grazing forest, and water body. Following that, different accuracy assessments were conducted, including user accuracy, producer accuracy, overall accuracy, and Kappa coefficient, which reflects how well the classification or estimated value corresponded with the real values.

2.5.1. Grain-size analysis of riverbank material

Bank martial samples were collected for all study sections of the study reach except section three at the top, middle, and bottom of the riverbank from January 22-2021 to January 26-2021 and wet sieve analysis was conducted to determine the bank material grain size, i.e., percentage of gravel, sand, and clay. To do so, 1000 grams of dirt were collected from the site and rinsed using a 0.075 sieve size before being dried in an oven at 105°C for 24 hours. The sieve sizes used during sieving time ranged from 0.075 mm to 4.75 mm, or the total sieve sizes used were 4.75 mm, 2.36 mm, 2 mm, 1.18 mm, 0.6 mm, 0.5 mm, 0.3 mm, 0.15 mm, 0.075 mm, and finally pan. Sieving was done manually for 10 minutes, and the weight of the retained material in each sieve was measured. Determine the cumulative mass retained for each sieve, then calculate the percentage of retained and percentage of finer for each sieve, then use log paper to make the percent of finer vs particle diameter graph. Calculate D60, D30, and D10 using the drawn graph, then calculate the coefficient of uniformity (Cu) and coefficient of curvature (Cc) using the formulas (D60÷D10) and $(D30)^2 \div (D60*D10)$, respectively, where D60, D30, and D10 are the particle size diameters equivalent to 60, 30 and 10% of the total particle size distribution curve, respectively.

3.0. Result and Discussion

3.1. Land use Land cover change

For this study, LULC assessment was required to see the effect of watershed change on river morphological change, so land use land cover change types were classified into five classes as shown in Table (5), and after classifying the LULC, different accuracy assessments were conducted, i.e., user accuracy, producer accuracy, overall accuracy, and kappa coefficient Table (1-4). Thus, accuracy assessment values informed us how much the classified LULC type agreed with the ground truth, and the process was carried out using 82 and 74 ground control points and Google Earth of 2013 and 2020, respectively, then after processing the accuracy assessment the kappa coefficient value of two assessment years (2013 and 2020) were 0.74 and 0.81, indicating that the classification was nearly accurate because it was within the standard value. The kappa value is one of the most commonly used statistics for testing the consistency of agreement in a situation. It ranges from -1 to 1, with 1 representing perfect agreement and -1 indicating less than chance agreement (McHugh, 2012). According to Cohen (1960), values 0 indicate no agreement, 0.01–0.20 indicate none to slight agreement, 0.21–0.40 as fair, 0.41– 0.60 as moderate, 0.61–0.80 as substantial, and 0.81– 1.00 as almost perfect agreement. See Table (1 and 3) for more information on calculating the accuracy assessment of the assessment year (2013 and 2020).

Table 1. Land use land cover change accuracy assessment for 2013

User image (2013)	Vegetation	Settlement	Agricultural	Water body	Grazing	Row total
Vegetation	**12**	0	1	0	1	14
settlement	1	7	4	0	2	14
Agricultural	4	1	**34**	0	0	39
Water body	0	0	1	**7**	0	8
Grazing	0	0	0	0	**7**	7
Column total	17	8	40	7	10	**82**

1. Overall Accuracy $= \frac{\sum(\textbf{Number of corrected value})}{\textbf{Total number of Reference}} * 100$ = (12+7+34+7+7)/82= 67/82=82.7%

Table 2. User and producer accuracy for 2013

Land use type	Row total	Column Total	Diagonal value	User accuracy	Producer accuracy	Assessment year
Vegetation	14	17	12	86%	71%	2013
Settlement	14	8	7	50%	88%	2013
Agricultural	39	40	34	87%	85%	2013
Water body	8	7	7	88%	100%	2013
Grazing	7	10	7	100%	70%	2013

Kappa Coefficient $= \frac{\mathbf{82*67-\sum(14*17)+)14*8)+(39*40)+(8*7)+(7*10)}}{\mathbf{(82)^2-(\sum\sum(14*17)+)14*8)+(39*40)+(8*7)+(7*10)\,)}}$ = 0.74

Table 3. Land use land cover change accuracy assessment for 2020

User image (2020)	Vegetation	Grazing	Agricultural	Water body	Settlement	Row total
Vegetation	**9**	0	0	0	0	9
Grazing	0	**6**	0	0	0	6
Agricultural	2	1	**25**	**0**	2	30
Water body	0	0	0	**8**	0	8
Settlement	0	0	6	0	**15**	21
Column total	11	7	31	8	17	74

Overall Accuracy $= \frac{\textbf{Number of corrected value}}{\textbf{Total number of Reference}} * 100$= (9+6+25+8+15)/74 = 63/74=85%

Table 4. User and producer accuracy result for 2020

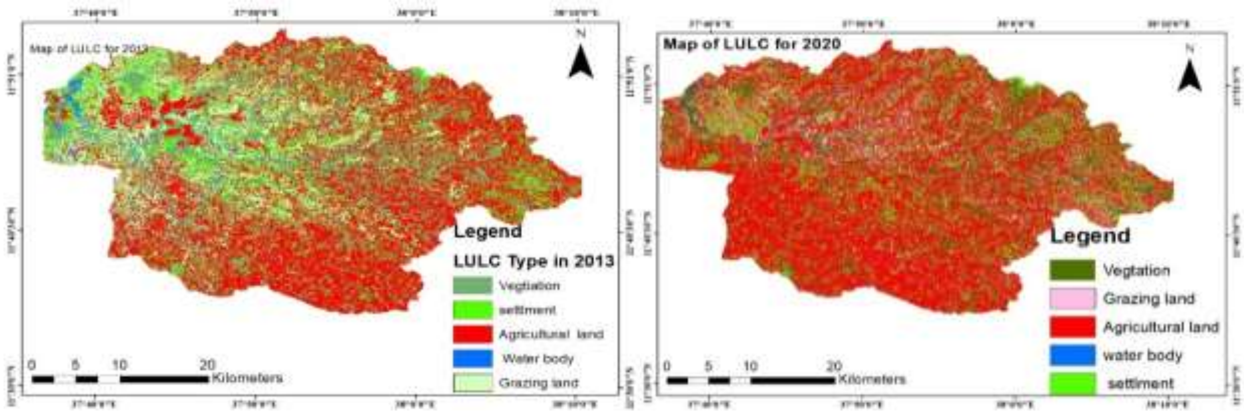
Land-use type	Row total	Column Total	Diagonal value	User accuracy	Producer accuracy	Assessment year
Vegetation (1)	9	11	9	100%	82%	2020
Grazing (2)	6	7	6	100%	86%	2020
Agricultural (3)	30	31	25	83%	81%	2020
Water body (4)	8	8	8	100%	100%	2020
Settlement (5)	21	17	15	71%	88%	2020

Kappa coefficient $= \frac{\mathbf{74*63-[(9*11)+(6*7)+(30*31)+(8*8)+(21*17)]}}{\mathbf{(74)^2-[([(9*11)+(6*7)+(30*31)+(8*8)+(21*17)]}}$ = 0.81

Table 5. Land use Land cover classification and change detection of the study area

LULC type	LULC detection result		
	2013(ha)	2020 (ha)	overall (%) change
Agricultural land	59999.92	79650.16	32.8
Grazing land	27141.12	14587.44	-46.3
settlement	23600.97	23710.17	0.5
Vegetation	25430.08	18280.96	-28.1
Water body	2189.52	2132.88	-2.6
Grand Total	138361.61	138361.61	0.0

The land use land covers analysis result of the study area shows an agricultural land increase by 32.8%, settlement increase by 0.5%, however vegetation and Grazing land decline by 28. 1% and 46.3% respectively. Now the result informs us study area was highly dominated by agricultural land, these intensive agricultural practices decrease forestation and consequently increase sediment supply from the elevated area, river instability, widening, avulsion frequency, and flood peak. The Human settlement was also the factor for the dynamical change of the river and, which has an important feature of any landforms, and with an increase in the population would be always a demand for land and human settlement. This encourages reduces the area under cultivation and fertile lands (Perumal & Jayaprakash, 2014). On the other hand, James & Lecce (2013) informed us Land use by human beings obviously can produce the hydrologic and geomorphic responses of the watershed and which is primarily altered the hydrogeomorphology of the natural river system. This was because Upper part land use disturbs the basic watershed process and causes excessive runoff or sediment production of the main river channel. Any human activity that disturbs vegetation and destabilizes soils have the potential to decrease soil infiltration, groundwater recharge, and intensify run-off generation and flood magnitudes. within the study area the dominant societies are farmers and source of income is direct with farming and source of the domestic fire was from bushes or forests and this usage continuous forever unless it is changed by modern means, so this social intervention accelerates loss of fertile soil in a watershed and increases the impervious extent of a watershed. The impervious nature of the land surface is more or less directly related to agricultural and settlement development or human intervention. Now the land use land cover change through time initiates the erosion problem within the watershed at high gradient and deposition at a low gradient, this also leads the natural river to lose its shape and dynamically changed either laterally or vertically through time. due to this fact we conclude that land use land cover was one of the divers for the change of upper reach Gumara river.



(a) (b)

Fig 5.Map of LULC for 2013 (a) and 2020(b)

3.2.Morphological chractrization &change detection

For morphological characterization and change detectionVarious researchers including (Alam et al., 2007),(Fuller& Brierley, 2013),(Marola & Comănescu, 2018),(Burele et al., 2014),(Dragićević et al., 2017) ,(Hossain et al., 2013),(Baki & Gan, 2012),(Akhter et al., 2019),(Abate et al., 2015) , (Mulatu et al., 2018) and (Midha & Mathur, 2014) used sevral parameters, including bank line, stream length, sinuosity index, and braided index, Area of the river neck length and etc. The utilization of full information on system dynamics, as well as the size and rate of channel change, is obtained by measuring morphological or planform change using various indices across time (Fuller & Brierley, 2013).

3.2.1. Stream length

Stream length is the curvilinear distance measured at the center of the stream, and the percentage of change was determined to see the time-series change of stream length, as shown in Table (1). The percentage change in stream length is confirmed by the amount in parentheses.

Table 6. Actual /stream length changes and section based average sinuosity from 1957 to 2020

Section	Stream Length (m)					
	1957	1999	2006	2013	2020	Over all % change
1	12031	12397 (+3)	12407 (+0.1)	12511(+0.8)	12590 (+0.6)	+4.6
2	4173	4178 (+0.1)	4188 (+0.2)	4292 (+2.5)	4370 (+1.8)	+4.7
3	5470	5476 (+0.1)	5486 (+0.2)	5590 (+1.9)	5670 (+1.4)	+3.7
4	8860	8866 (+0.1)	8876 (+0.1)	8990 (+1.3)	9060 (+0.8)	+2.3
5	8380	8386 (+0.1)	8396 (+0.1)	8500 (+1.2)	8580 (+0.9)	+2.4
6	6391.85	6874.53(+7.6)	6882.68 (+0.1)	6973.18 (+1.3)	7066.00 (+1.3)	+10.5

Table (1) shows that the change in the actual length was oscillating, with a positive and negative number in parenthesis indicating an increase and reduction in the time series percentage length, respectively. The overall percentage change analysis result of stream length from 1957 to 2020 was 4.6 %, 4.7 %, 3.7 %, 2.3 %, 2.4 %, and 10.5 % for each section (1,2,3,4,5, and 6) of the study reach. The positive percentage change in stream length indicates that the river has taken on a more meandering character. Furthermore, the longer the actual /stream length, the more the river flows via the longest course; as a result, the river's bed slope decreases, which fosters the formation of sand bars inside the river. The steeper the slope, the more aggradation of the downstream riverbed and erosion of the riverbank, and this is a mechanism or indicator for changes in river Plan shape. Table 1 shows that the more the Stream length, the greater the sinuosity index, which suggests that the reach is more meander and that slope and sinuosity are negatively associated. The overall temporal variation in stream length of the study reach was calculated in addition to section-based stream length. This means that the entire study reach can be viewed as a single piece, beginning at the outlet and ending at the inlet or endpoint. As a result, the stream length has increased by 4.48 %.

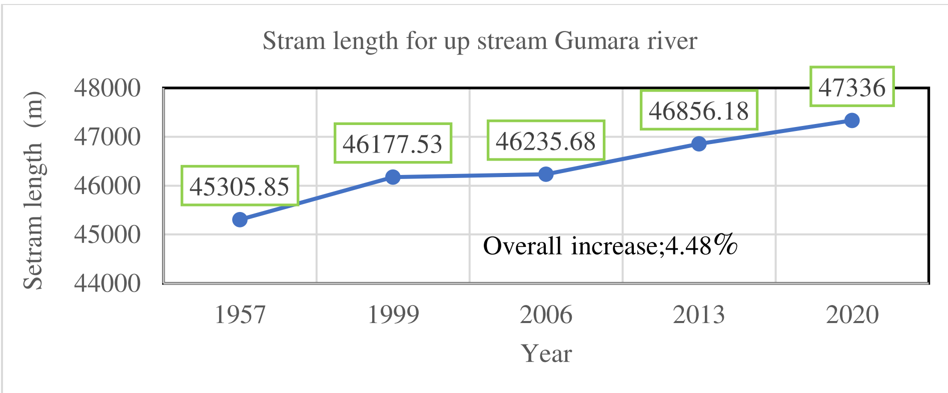


Fig 6.Temporal variation of the stream length

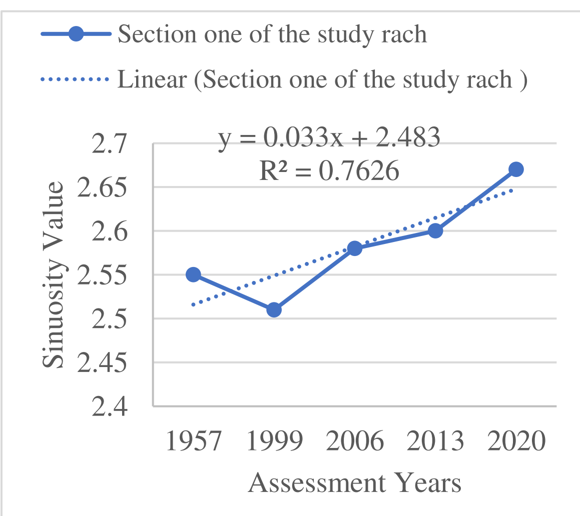
3.2.2. Channel sinuosity

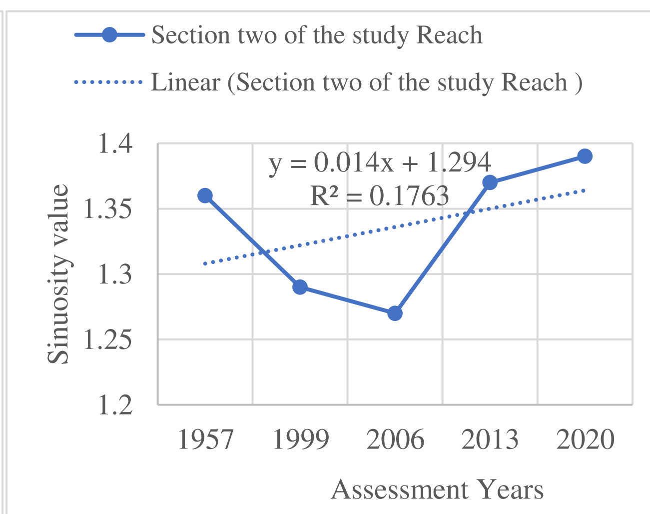
Sinuosity is a quantitative stream index that measures the river's meandering and characteristic properties. It can be measured using the ratio of Actual River length to Valley length or straight-line length, as stated on the preceding page. This index provides information on the dynamical status of the periodic river throughout its history. The whole research reach length should be separated into several subsections utilizing GIS technologies to obtain the sinuosity index for each of the study reach or portions for each study year. The technique of such river length split allows us to readily estimate the sinuosity of each segment of the study reach, as well as to gain a complete grasp of the river's dynamism at each section. From the overall Sinuosity Analysis Fig (6) the upper reach Gumara River's average sinuosity was 2.37 in 1957, 2.4 in 1999, 2.43 in 2006, 2.47 in 2013, and 2.5 in 2020. The higher and lower values in the sinuosity study suggest significant meandering and a high propensity for erosion in each segment of the reach. The percentage change in sinuosity from (1957-2020) was also estimated to see how the overall sinuosity of the upper reach Gumara river evolves over the research period. From (1957-1999), the computed value fluctuated by 1.27%, 2.53% from (1957-2006), 4.22% from (1957-2013), and 5.49% from (1957-2020). The total sinuosity change for the upper and lower reaches of the Gumara River can be compared using this overall percentage change study. For the lower reach of the Gumara river Abate et al (2015) calculated the sinuosity of a 38-kilometer stretch of the river by dividing the study reach into four portions from 1957 to 2006. According to that study, the percentage change of each section of study reaches and the total percentage change were calculated from 1957 to 2006, and the total percentage change of sinuosity for the lower reach of the Gumra River was 1.48%. This means that the sinuosity of the lower

Gumara river increased by 1.48% in 2006 compared to the sinuosity of 1957; nevertheless, the total percentage rise in sinuosity for the upper Gumara river was 5.49% between 1957 and 2020. The sinuosity value was oscillating considerably in all six sections during various evaluation periods, according to section-based sinuosity analysis in Table (2). For each Assessment year, the sinuosity of all study sections was greater than or equal to 1.25, indicating a meandering pattern. Sinuosity was lost by 1.6% at section one during the assessment year 1957-1999, by 5.2% at section two during the same assessment year, and by 1.6% at section two and 0.8% at section three during the period 1999-2006. Finally, sinuosity was lost by 0.6 % at section five during the assessment year 2013-2020. The sinuosity was gained at each of the study sections throughout the remaining evaluation years. The percentage change was 4.71% at section one, 2.21% at section two, and 4.8% at section three. Sections four, five, and six, respectively, increased by 3.26%, 6.44%, and 7.94% over 64 years. According to the total reach-based sinuosity analysis result. The increase in river curvature, as indicated by the temporal change in sinuosity, may facilitate the rate of bank erosion, causing the river to meander.

Table 7: Reach based percentage change of sinuosity index (1957-2020)

Section	sinuosity					
	1957	1999	2006	2013	2020	Overall (%) change
1	2.55 (0)	2.51 (-1.6)	2.58 (+2.8)	2.6 (+0.8)	2.67 (+2.7)	4.71
2	1.36 (0)	1.29 (-5.2)	1.27 (-1.6)	1.37 (+7.9)	1.39 (+1.5)	2.21
3	1.25 (())	1.29 (+4.0)	1.28 (-0.8)	1.28 (0.0)	1.31 (+2.3)	4.8
4	1.84 (0)	1.87 (+1.6)	1.88 (+0.5)	1.89 (+0.5)	1.9 (+0.5)	3.26
5	4.66 (0)	4.85 (+4.1)	4.94 (+1.9)	4.99 (+1.0)	4.96 (-0.6)	6.44
6	2.52 (0)	2.56 (1.6)	2.63 (2.7)	2.66 (+1.1)	2.72 (2.3)	7.94





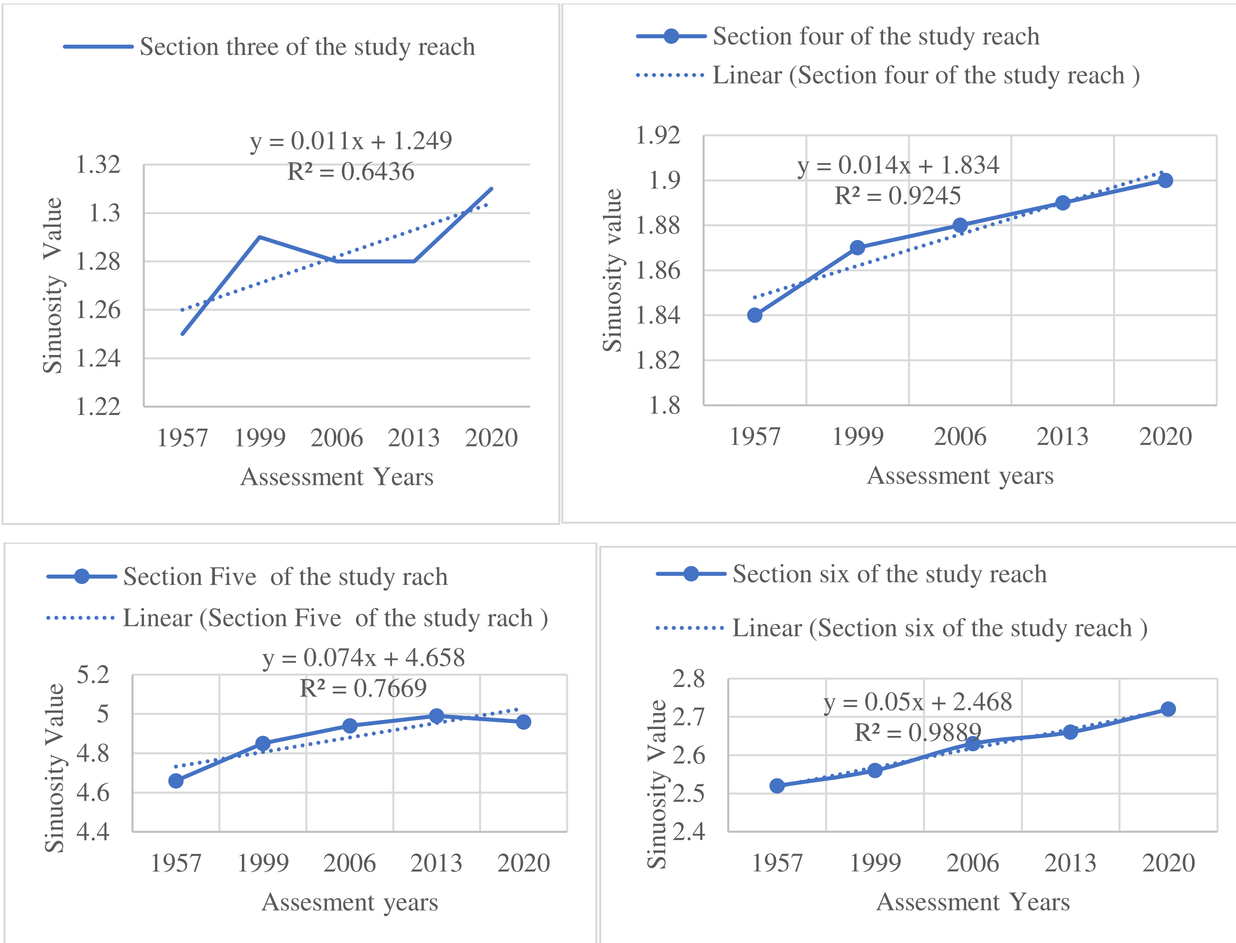


Fig 7. Section based temporal variation of sinuosity index for upper reach Gumara River

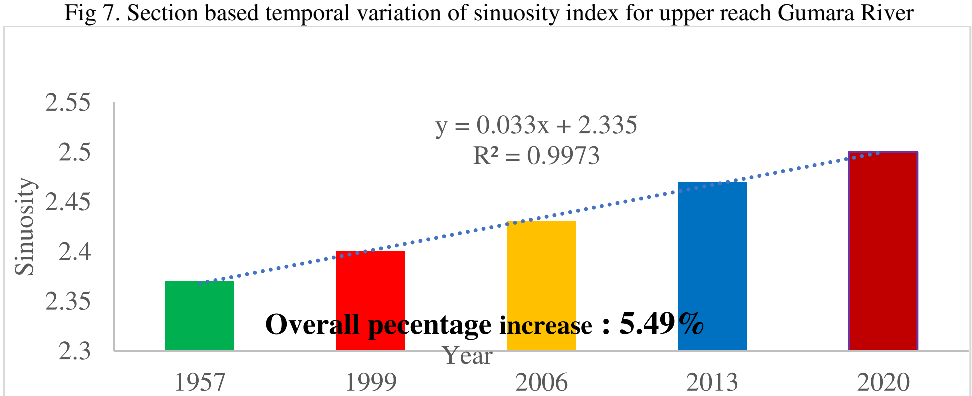


Fig 8.Average temporal variation of sinuosity index analysis result

According to the previous section's all-over sinuosity analysis in Fig (6) and its trend line in Fig (5) results, the magnitude of the river's sinuosity is increasing over time. This time-sequential sinuosity variation is a marker of the upper Gumara river's planform dynamics. The increased sinuosity, on the other hand, increases the likelihood of a chute or neck cutoff formation. Furthermore, the higher the river's sinuosity, the more the river detects the characteristics of the river basin's gentle slope, indicating that the area is becoming more vulnerable to flooding (Gautam, 2019). The explanation for this is implies that, a larger sinuosity indicates that the river has a longer stream length, which reduces the slope of the stream or creates a moderate slope, reducing movement within the river and encouraging sediment deposition rather than conveyance. Finally, various bars may form, posing a threat to the surrounding environment by flooding it and destroying both living and nonliving things.

3.2.3. Braidedness index

Due to bar formation, the braided river comprises many flow lines, and the river channel is a dynamic system with high rates of fluvial activity and channel change from erosional and depositional processes. The Braided index is used to determine the degree of braided stream network development and to quantify how such a pattern changes over time. A reach length of at least 10 times the average wetted width was required to measure the braided index (Egozi & Ashmore, 2016). The study reach, on the other hand, was braided at fixed points of section four and two in this case. As a result, the length of the segment used to calculate the braided index was determined using the bar distribution. According to Sarma & Acharjee, 2018)), the river's braided index must be greater than 1.5 for it to be braided. Using this reality, values of BI indicate a growing trend for the nominated portion of the upper reach Gumara river, as illustrated in the Figure below.

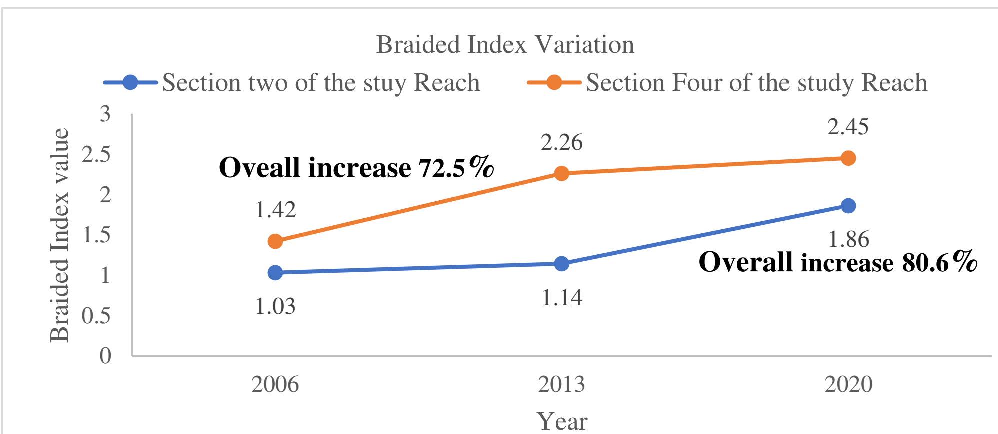


Fig 9.Average Braided Index distribution at section two and four of study reach

The steady change in the braided index suggested that a significant amount of sediment had been deposited in that location, the river width had expanded, and the section was more distributed than other sections of the investigation. reach.

3.2.4. Center Line Migration of the study Reach

The centerline of a river can be defined as its midpoint along its length, and river centerline movement can be used to measure lateral shifting. It indicates the dynamical change of the channel system, and the centerline of a channel changes temporally primarily due to the channel's siltation problem (Agnihotri et al., 2020). In the case of upper reach Gumara, the centerline was oscillated towards the right (R) and left (L) directions relative to the centerline, in 1957 indicating that the river was changed with time. The average rate of centerline migration (m/year) for each subsection of the study reach (1, 2, 3, 4, 5, and 6) measured at 1km intervals are shown in the table below.

Table 8. Average lateral shifting of the center line for upper reach Gumara River

Years of interval	1957-1999		1957-2006		1957-2013		1957-2020	
Section	R	L	R	L	R	L	R	L
1	0.67	0.88	0.58	0.91	0.46	0.48	0.45	0.57
2	0.22	0.30	0.20	0.03	0.33	0.11	0.18	0.15
3	0.56	0.27	0.62	0.37	0.13	0.22	0.16	0.18
4	0.00	0.79	0.28	0.58	0.35	0.51	0.24	0.38
5	0.38	0.64	0.61	0.37	0.50	0.35	0.53	0.19
6	0.66	0.39	0.00	0.53	1.10	0.36	0.31	0.59
Maximum shift (m/yr.)	0.67	0.88	0.62	0.91	1.10	0.51	0.53	0.59
minimum shift(m/yr.)	0.00	0.27	0.00	0.03	0.13	0.11	0.16	0.15
standard deviation (m/yr.)	0.27	0.26	0.26	0.29	0.33	0.15	0.15	0.20

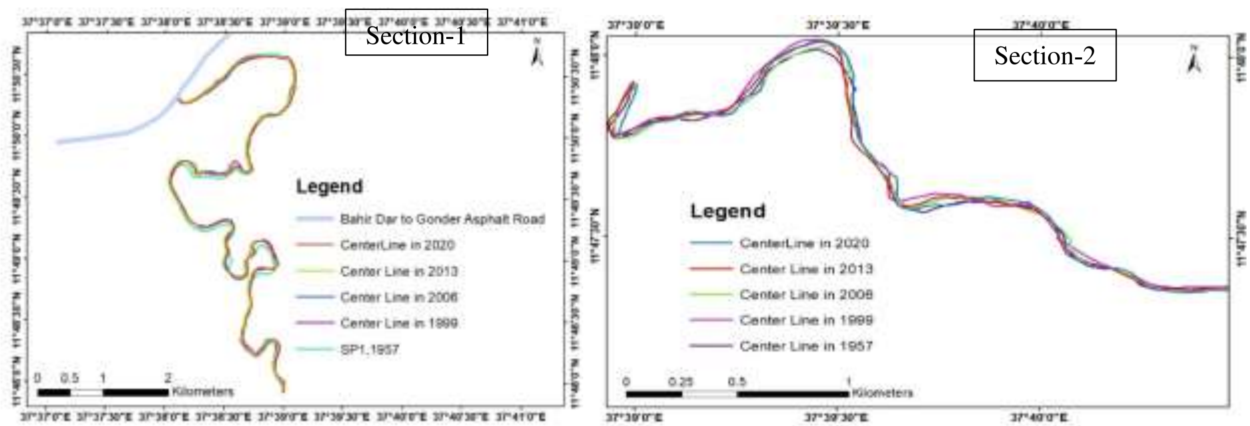


Fig 10.. Map of center line at section one and two of the study reach

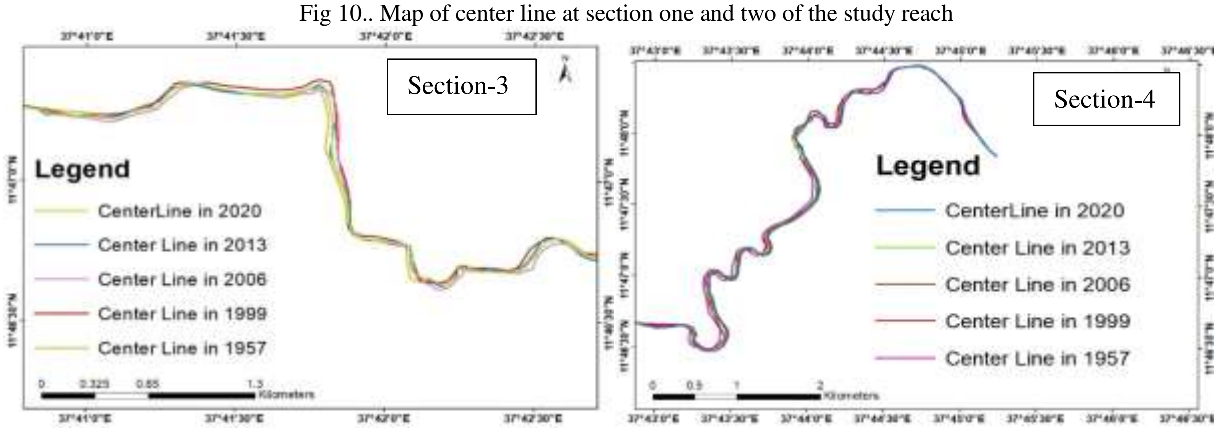


Fig 11. Map of center line at section thee and Four of the study reach

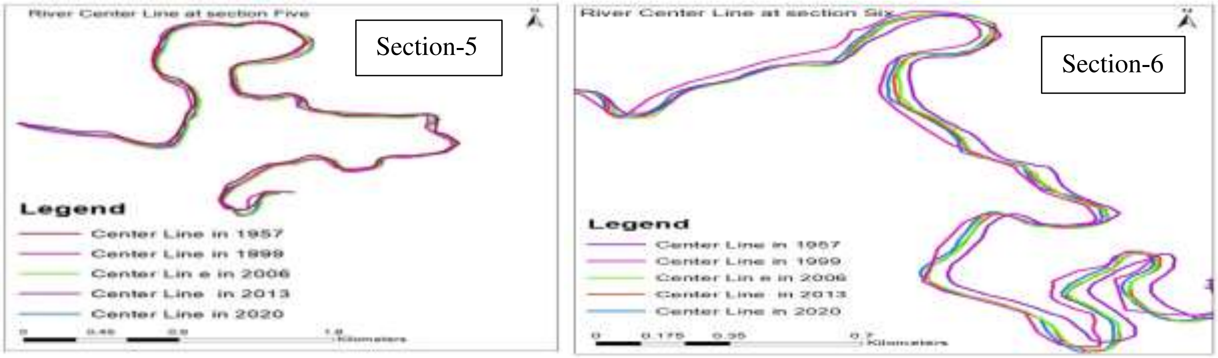
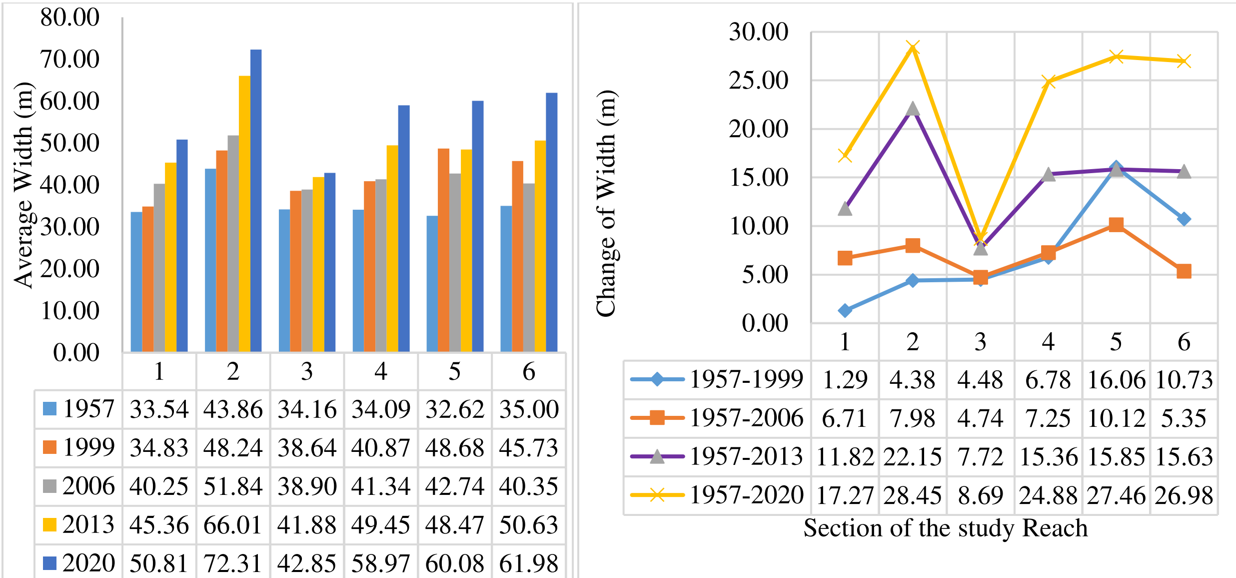


Fig 12.Map of center Line at Section five and six of the study reaches

Various anthropogenic and natural factors stretched, stiffened, and attuned the upper reach of the Gumara River during the study period. The efficient mapping of river Centerline for the period 1957-2020 reveals that the upper reach of the Gumara River regularly shifted from left to right and vice versa. Section one of the study reach migration towards the left from 1957 to 1999 with a maximum value of 0.88m/year and from 1957 to 2006, the maximum average shift was also to the left direction at section one with the value of 0.91 m/year. However, at section six of the study reach, the largest average shift was towards the right direction by 1.1 m/year from 1957 to 2913. Finally, at section six, the highest movement from 1957 to 2020 was 0.59 m/year to the left. Here the all over average centerline shift indicates that the shift was totally to the left direction and Qualitatively from the overlapped map of the centerline in Fig (8 to 10), the centerline at time one never fit with the centerline at time two this is also one of the signs of the dynamic change of the upper reach Gumara river through time.

3.2.5. Status of Width for upper reach Gumara River

River width was used as a parameter for measuring the status of the natural river in terms of time and space (Esfandiary & Rahimi, 2019). The total width of the upper Reach Gumara River that, tabulated in Fig (13) was calculated using arc GIS 10.5 and yielded a maximum width of 72.31 m at section two of the study reach over the entire assessment period. The average width was varied from 35.54 m to 42.83 m between 1957 and 1999, 42.83 m to 42.57 m between 1999 and 2006, 42.57 m to 50.0 m between 2006 and 2013, 50.0 m to 57.83 m between 2013 and 2020 57.83 m. Here the aveage width was decrease by 0.26 m form 1999 to 2006 and this indicates that, between 1999 and 2006 deposition was dominate, however the over all average width was increase by 0.348 m/yers over 64 years . Therefore, the overall and section-based width analysis indicates that the width of upper reach Gumara was increase and the change of width was both spatially and temporally.

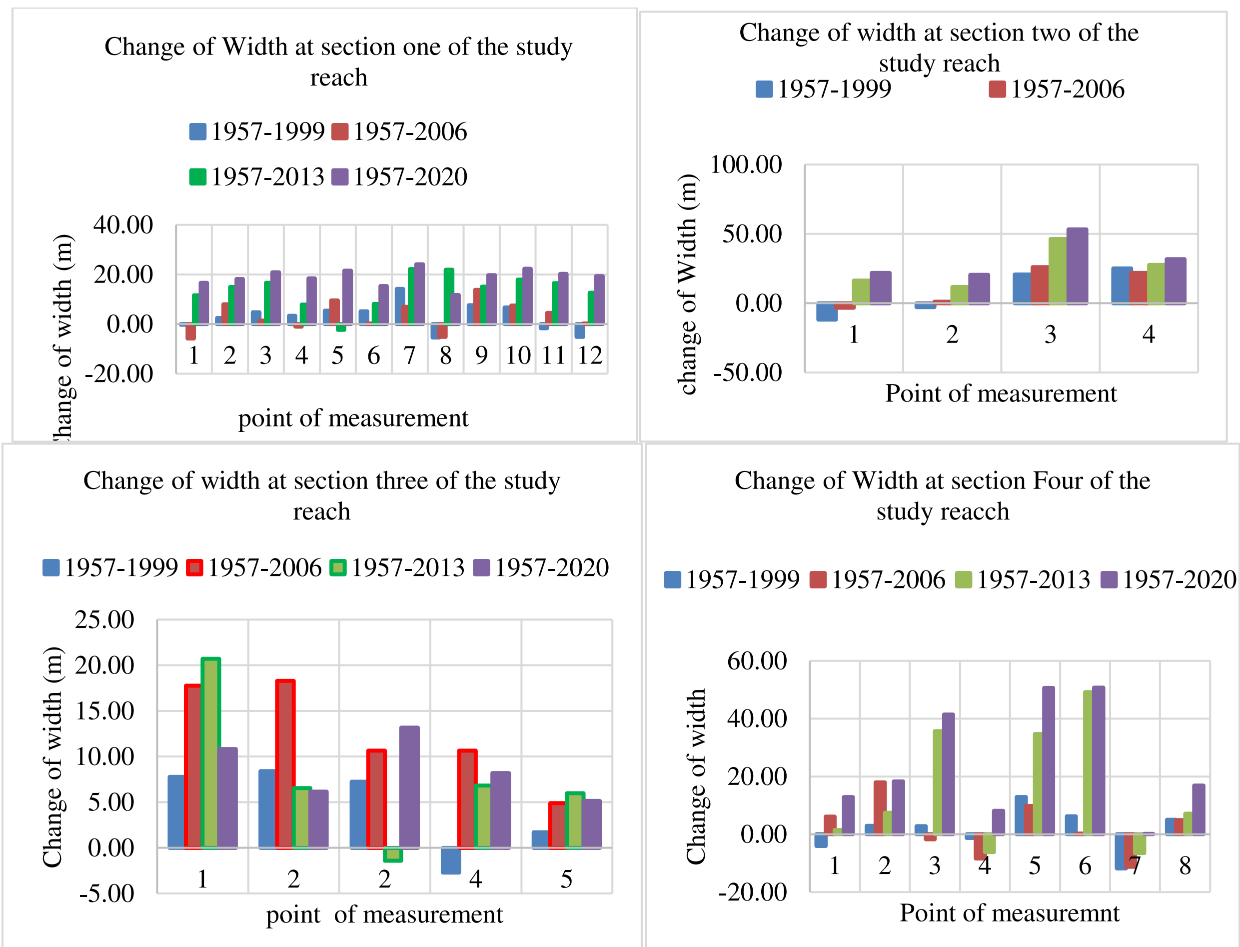


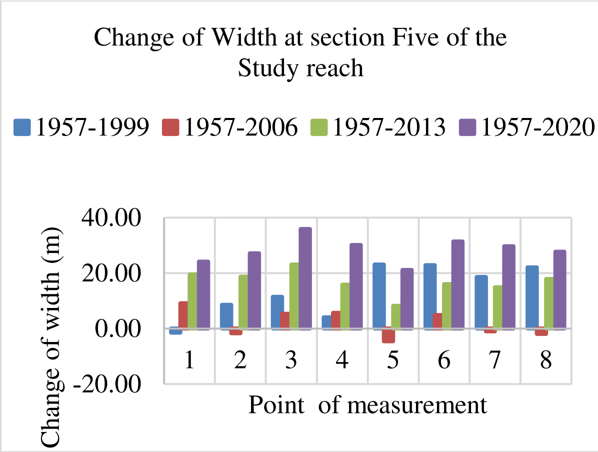
	1	2	3	4	5	6
1957	33.54	43.86	34.16	34.09	32.62	35.00
1999	34.83	48.24	38.64	40.87	48.68	45.73
2006	40.25	51.84	38.90	41.34	42.74	40.35
2013	45.36	66.01	41.88	49.45	48.47	50.63
2020	50.81	72.31	42.85	58.97	60.08	61.98

	1	2	3	4	5	6
1957-1999	1.29	4.38	4.48	6.78	16.06	10.73
1957-2006	6.71	7.98	4.74	7.25	10.12	5.35
1957-2013	11.82	22.15	7.72	15.36	15.85	15.63
1957-2020	17.27	28.45	8.69	24.88	27.46	26.98

(a) (b)

Fig 13. Spatio-temporal Average width Distribution (a) and Overall average change of width (b)for the study Reach





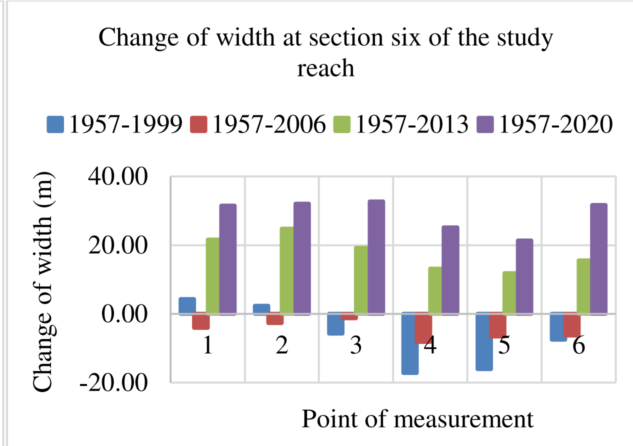


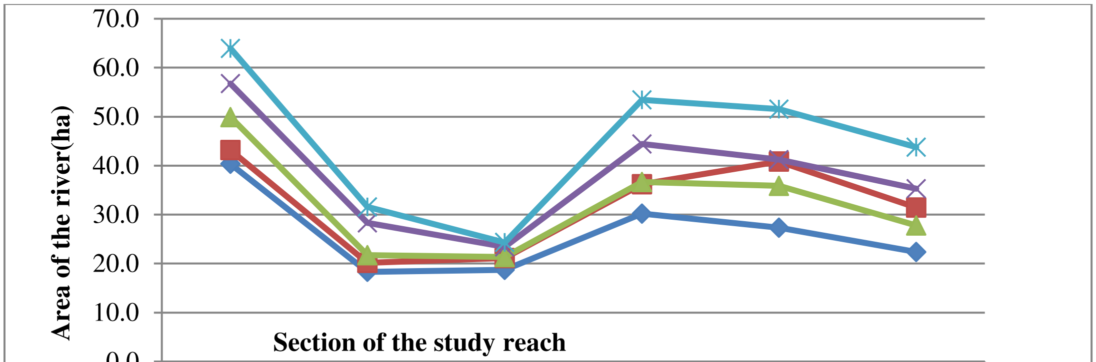
Fig 14.Change of width at each Section of the Study Reach at 1km Interval

3.2.6. Planimetric area variation

The rate of change of area for each section of the study reach (1, 2, 3,4 ,5, and 6) illustrated in table (9) from 2006-2020 varied 0.37 m/yr,0.21 m/yr, 0.09 m/yr, 0.36 m/yr, 0.38 m/yr, and 0.33 m/yr respectively. Now according to the result, the negative value indicates that , the river was experienced deposition for that study years and the positive value means the river experienced erosion problems. Furthermore, the time variation of the planimetric area of the river indicates how match flood plain is gained or lost in that time, which means that the negative area indicates how match floodplains was gained in that study year and section and a positive value means that how match floodplains was lost in that study year and section.

Table 9 . Overall change of planimetric Area of the study reach

No. section	Area (ha)					
	1957	1999	2006	2013	2020	Rate of change
1	40.4+0	43.2 (+2.8)	49.9 (+6.8)	56.7 (+6.8)	64.0 (+7.2)	0.37
2	18.3+0	20.2 (+1.9)	21.7 (+1.6)	28.3 (+6.6)	31.6 (+3.3)	0.21
3	18.7+0	21.2(+2.5)	21.3 (+0.2)	23.4 (+2.1)	24.3 (+0.9)	0.09
4	30.2+0	36.2 (+6.0)	36.7 (+0.5)	44.5 (+7.8)	53.4(+9)	0.36
5	27.3+0	40.8 (+13.5)	35.9 (-4.9)	41.2 (+5.3)	51.5 (+10.3)	0.38
6	22.4+0	31.4 (+9.1)	27.8 (-3.7)	35.3 (+7.5)	43.8 (+8.5)	0.33



	1	2	3	4	5	6
1957	40.4	18.3	18.7	30.2	27.3	22.4
1999	43.2	20.2	21.2	36.2	40.8	31.4
2006	49.9	21.7	21.3	36.7	35.9	27.8
2013	56.7	28.3	23.4	44.5	41.2	35.3
2020	64.0	31.6	24.3	53.4	51.5	43.8

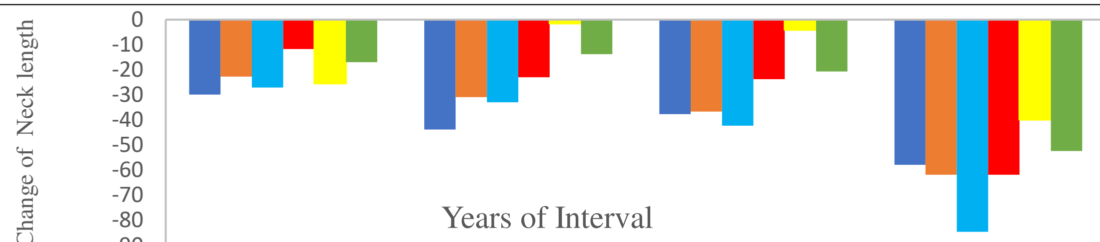
Fig 15. Spatio -temporal change of Area for the study reach

3.2.7. Change of Neck length

The the sequential variation of the neck length shown by the trend line Fig (11) indicates in diminishing manner and to detect spatio-temporal variation of the neck length for the nominated study section percentage change of neck length was calculated raging from 1957 to 2020 and the result for each section of the study reach varies (-54%, -24%, -63%, -42%, -36%, and -48%) for each section of the study reach of (1, 2, 3, 4, 5, and 6) respectively. The negative indication shows that the length of the neck has shortened with time, which increases the likelihood of neck cutting and, as a result, creates a complete shift in the River's features. This was owing to the fact that the stream length decreased when the river was cut off at a given point. The eroding power of streamflow is increased when the stream length is reduced and the slope of the stream is increased. The growth of cut-off effects the morphology and dynamics of the meandering River in two ways, according to several scholars throughout the world (Hooke, 1995, Zinger et al., 2011, (Dieras, 2013). First, the active channel is impacted by the massive amount of sediment released as a result of the meander Neck breaching As a result of the shorter stream length and upstream Knick point migration, the channel gradient rises, and lateral migration may increase. On the other hand, it results in an uncontrolled channel reach created , which develops into an oxbow lake**.** Furthermore, neck cut-off increased bank erosion and channel widening in both upstream and downstream channels, owing to the fact that it raises sediment supply rates in upstream cases and limits the river's capacity downstream due to sediment-laden flow (Li et al., 2019).

Table 10. Result of Neck Length measurement for extreme bends of study Reach

No. section	Neck Length (m)					
	1957	1999	2006	2013	2020	overall (%) change
1	108.2	78.36(-28)	64.34(-18)	70.5(+10)	50.3 (-29)	-54
5	259.1	236.34(-9)	228.23(-3)	222.4(-3)	197.2(-11)	-24
between 5&6	135.3	108.3(-20)	102.3(-6)	93.01(-9)	50.7(-45)	-63
6(1)	146.4	134.7(-8)	123.38(-8)	122.68(-1)	84.6(-31)	-42
6(2)	127.6	102.2(-20)	126.06(+23)	122.02(-3)	82.2(-33)	-36
6(3)	108.6	91.6(-16)	94.9(+4)	87.9(-7)	56.2(-36)	-48



	1957-1999	1957-2006	1957-2013	1957-2020
Section -1	-29.84	-43.86	-37.7	-57.9
Section -5	-22.74	-30.85	-36.68	-61.88
between section 5&6	-27	-33	-42.29	-84.6
Section six of point -1	-11.7	-23.02	-23.72	-61.8
Section six of point -2	-25.4	-1.54	-4.04	-39.82
Section six of point -3	-17	-13.7	-20.7	-52.4

Fig 16. Change of neck length (1957-2020)

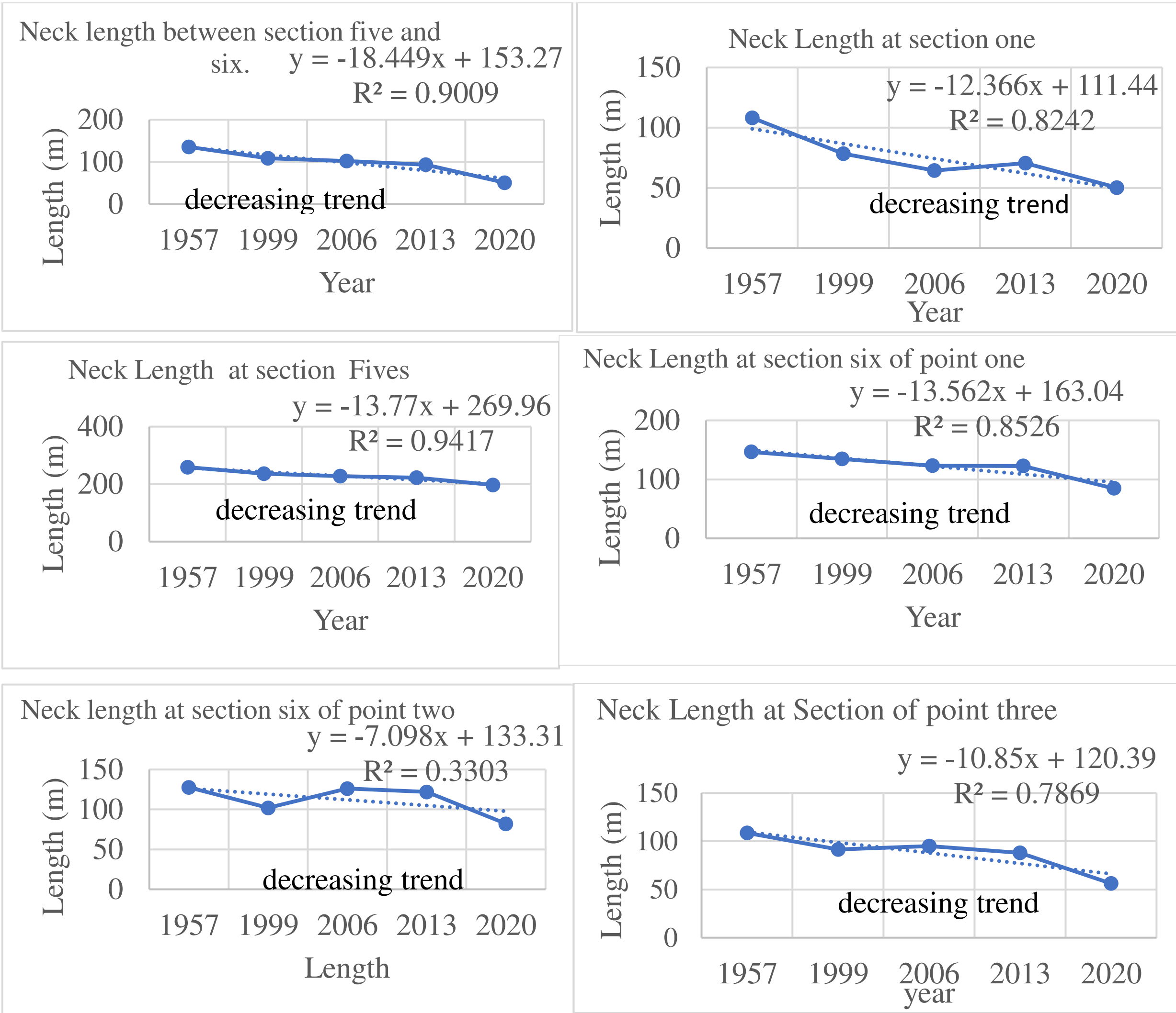
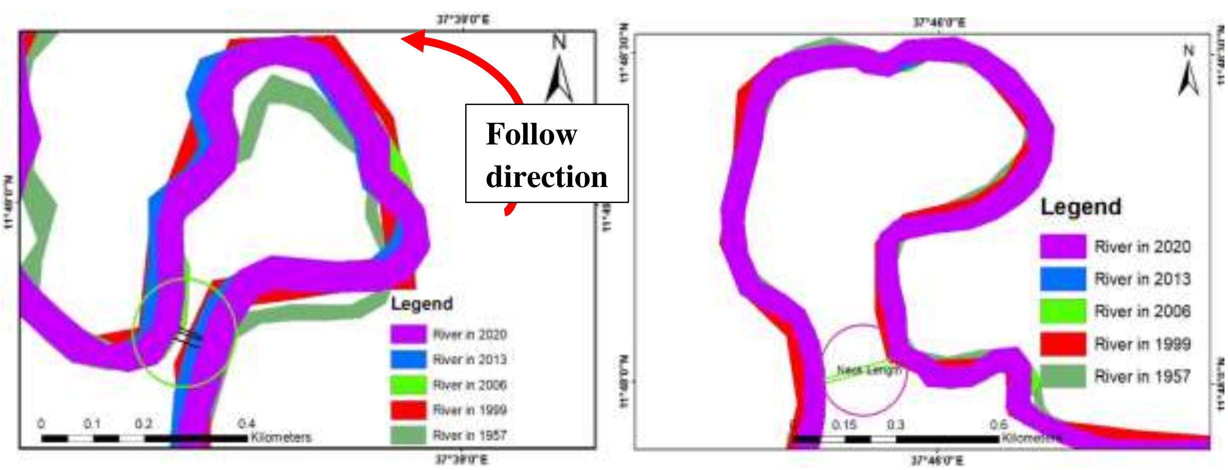
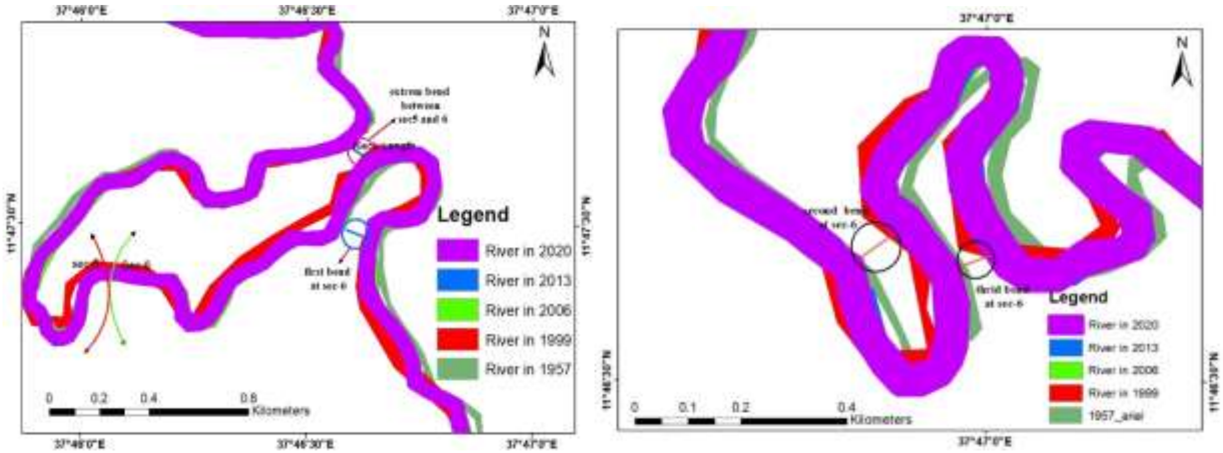


Fig 17. Temporal variation of neck length



a **b**

Fig 18. Map of extreme bend at section one(a) and five (b) of the study reach



a b

Fig 19. Map of extreme bend b/n section five and six (a) and section six (b) of the study reach

3.2.8. Riverbank Line shifting

The degree of river activities such as erosion, transportation, and deposition, the volume of river flow during peak flow time, soil and geological structure, and human intervention with the river are all factors that interact and interrelate in global direct bank line migration (Nabi et al., 2016). Similarly, both natural and anthropogenic actions disrupted and transformed the upper reach Gumara bank line, causing irreversible harm to agricultural land, infrastructure, and social institutions. River shifting can be measured in two ways around the world. Specifically, the transect and polygon approaches (Dhari et al., 2015). However, in this investigation, transect procedures were employed. In this study, Google earth image 2013 and Google earth image 2020 were used to measure the bank line shifting spot, and measurements were taken at 1 km intervals at 13 cross-sections for section one, 5 cross-sections for section two, 6 cross-sections for section three, 9 cross-sections for both section four and five, and 7 cross-sections for section six of the study reach. The bank line measurement result indicates that the bank line over seven years' time was oscillated in varying degrees for both Right and left banks. This means that the change in bank line from 2013 to 2020 specifies both positive and negative values, with the positive value indicating outward migration or erosion dominating, and the negative value indicating inward migration or deposition dominating. The average deposition and erosion phenomena of the bank line for each part of the study reach were determined using this idea. Section one's left bank has experienced 6.2 m erosion and 3.2 m deposition, section two has experienced 14.2 m erosion and 5.8 m deposition, section three has experienced 3.7 m erosion and 2.8 m deposition, section four has experienced only 10.1 m erosion rather than deposition, and section five has experienced 8 m erosion and 2.9 m deposition. The General information here is the study reach was mainly migrated two wards the left bank. The maximum erosion and deposition were registered at section four of the left bank and section one of the right banks respectively**.** To verify the ground truth a fixed structure was used to assess the rate of lateral movement and vertical degradation of the river bank. A water well was dug in the upper reaches of Section One in 1977 for the manufacturer of crops and animal feed's household use at 25 meters far from the main reach's left bank. The water well was now completely submerged in the river, 7.5 meters from the left bank and 4.5 meters above ground level. The message is that 4.5 meters of earth were removed and 32.5 meters were moved laterally over the sequence of 36 years (1977-2013). This implies that the lateral movement of the river bank in that segment was 0.903 m/year, or that the river degraded by 0.125 m/year. As a result, the water well distraction Fig (1b) strongly suggests that the upper reach Gumara River's dynamical shift has occurred, resulting in the loss of significant fertile agricultural land.

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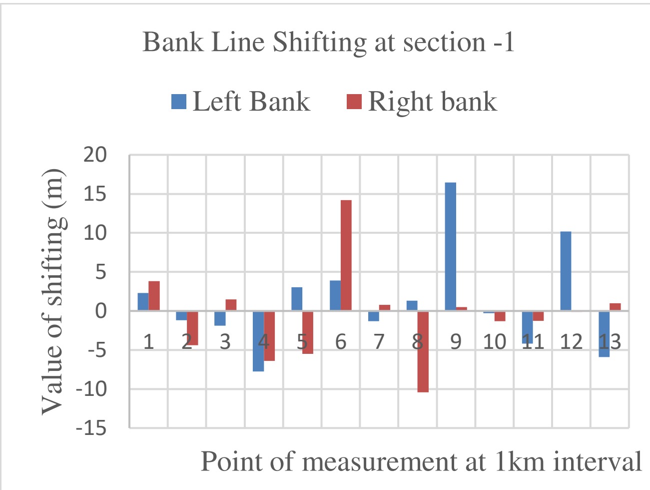
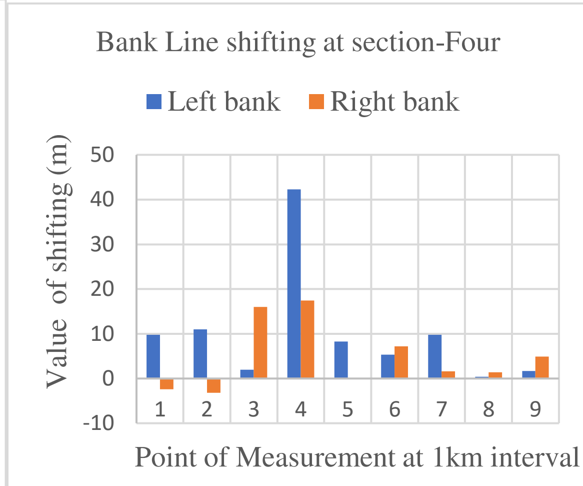
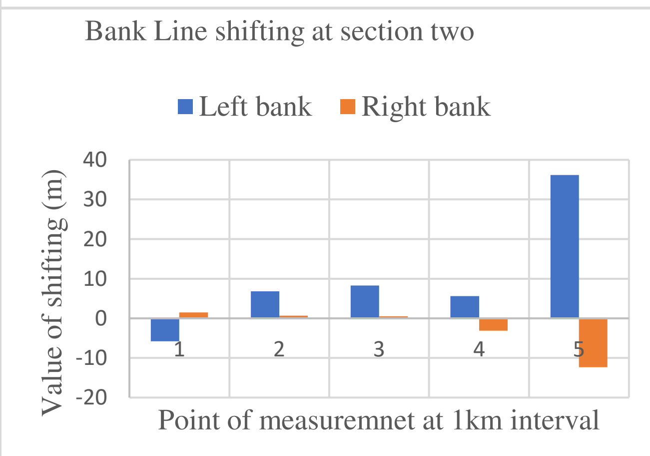
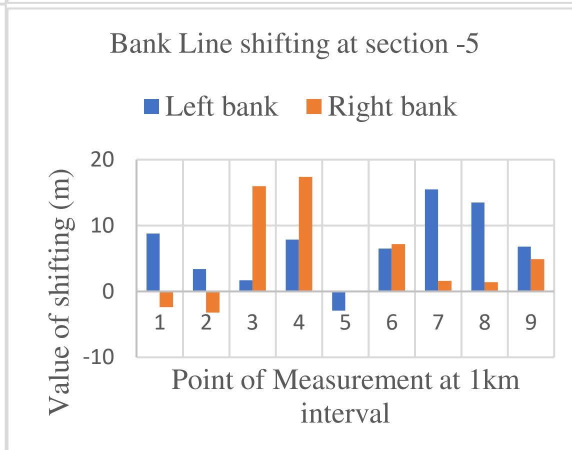








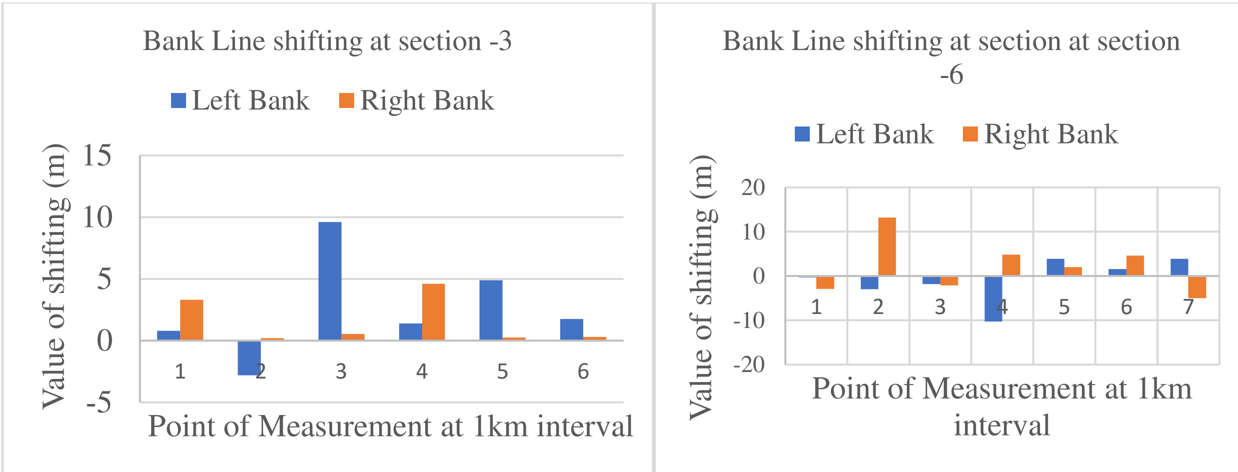
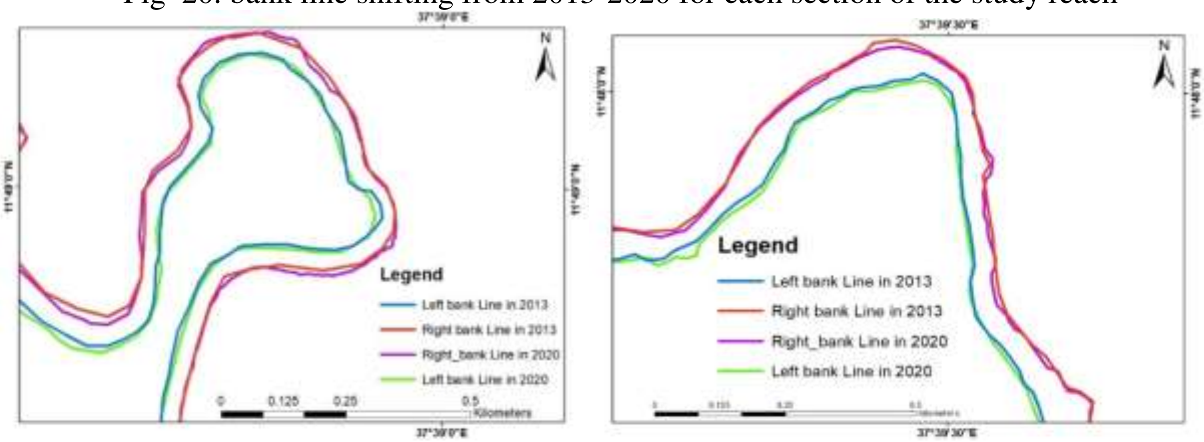
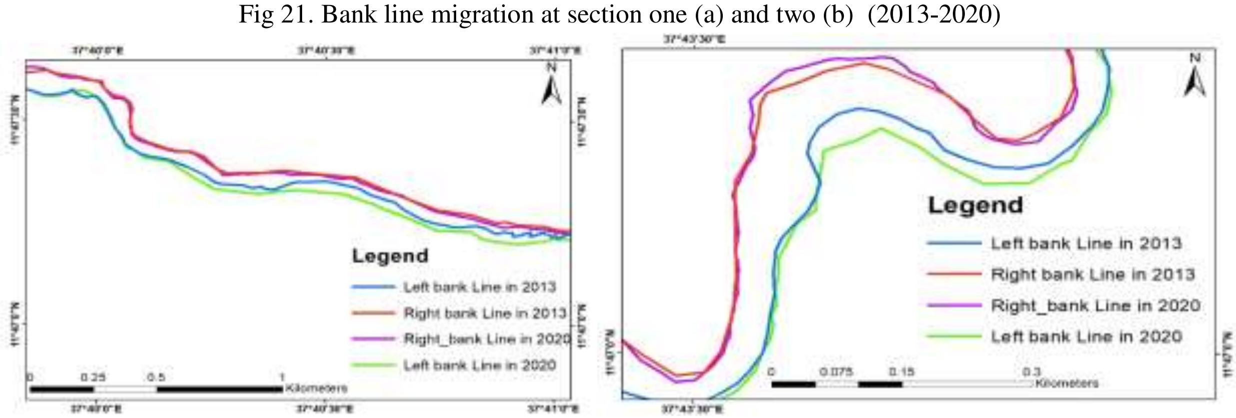


Fig 20. bank line shifting from 2013-2020 for each section of the study reach



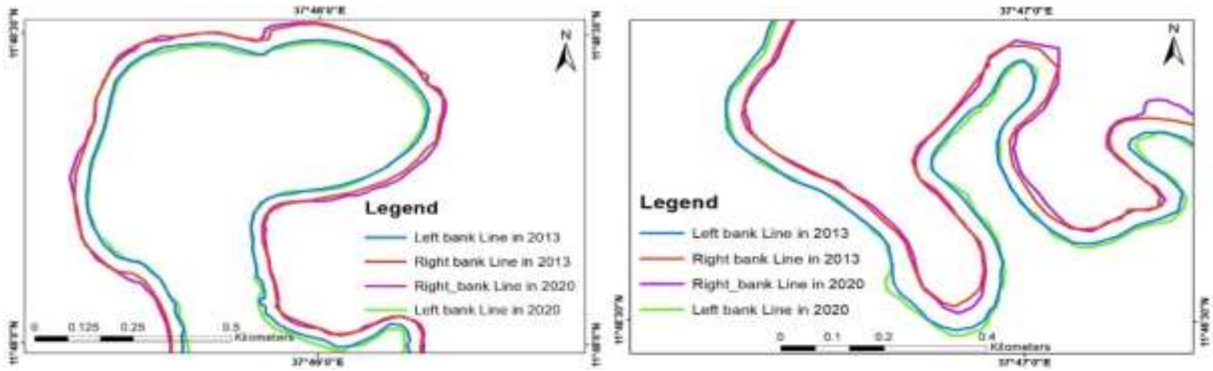
(a) (b)

Fig 21. Bank line migration at section one (a) and two (b) (2013-2020)



(a) **(b)**

Fig 22. Ways of river bank line migration for section three (a) and four(b) (2013-2020)



a **b**

Fig 23. Ways of river bank line migration for section five(a) and six (b) (2013-2020)

3.3. Driver which controls morphological change

Natural and anthropogenic factors devastate natural river systems. Rainfall, river flow, sediment transport, river bank material character, and bed material features are all natural drivers that are largely related to climate change; however, for this study, rainfall, stream flow, sediment concentration, and riverbank materials were used. Rainfall is an uncontrollable natural occurrence that disrupts geographical landscape characteristics and creates gullies in a watershed, promoting erosion power within the watershed. More silt is likely to be dumped into the river channel when the watershed's erosion potential is at its peak and consequently reducing channel capacity and causing natural channel alteration. Totally the rainfall trend line in Fig (3) is nearly homogeneous throughout the nominated years, whereas the stream flow trend line shows a slight increase relative to rainfall, indicating that the watershed was impervious to rainfall and much of it was directly changed to run off/flow. The availability of hydrological data, particularly stream flow and sediment concentration data, has been insufficient from the beginning to the present to assess their impact on plan form dynamics; however, even though stream flow and sediment concentration data were insufficient to assess their impact on plan form dynamics from 1957 to the present, the trend of the data used indicates a positive trend, and this informed us that stream flow and sediment concentration is the factor which lead the change.

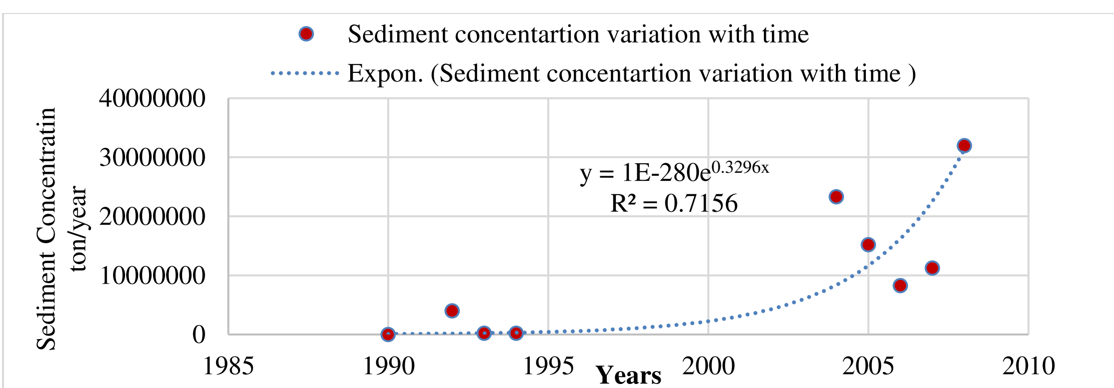


Fig 24. Sediment concentration distribution with time

According to Lemma et al. (2017), despite the fact that a large amount of sediment was discharged to the Take Tana from Ribb, Megech, Gilgle Abay, and Gumara, the dominant sediment was from Gilgle Abay and Gumara, indicating that sediment was one of the causes of the upper reach Gumara River's morphological change.

3.3.1. Riverbank Material Chracterstics

River banks, as we know, reproduce as a result of the interaction between the hydraulic action imposed by the river and the nature of river bank material. For the upper reach of the Gumara river, laboratory analysis results Fig (18 to 21) show that the bank material was predominantly sand, and sand by itself is a non-cohesive material, i.e., bank soil with a high percentage of sand leads to high erosion and eventually widening of the river channel, due to the fact that sand soil never resists the pressure produced by the force of the river water. Because sandy soil has a high angle of internal friction between each particle and so River water pressure easily disturbs it. This result indicates that the bank material was one of the drivers for all of the nominated sections of the study reach because various authors such as (Bhowmik et al., 2018) informed us bank material covering more than 90% sand and less silt and clay makes the soil non-cohesive, resulting in maximum erosion and eventually expanding the channel. The uniformity coefficient (Cu) value ranges between 3.8 and 0.9 and coefficient of curvature (Cc) value ranges 2.4and 0.74 This indicates that the bank material is poorly graded sand soil and the sandy soil is cohesion less soil and so the shear strength is less relative to cohesive soil and easily vulnerable to erosion.

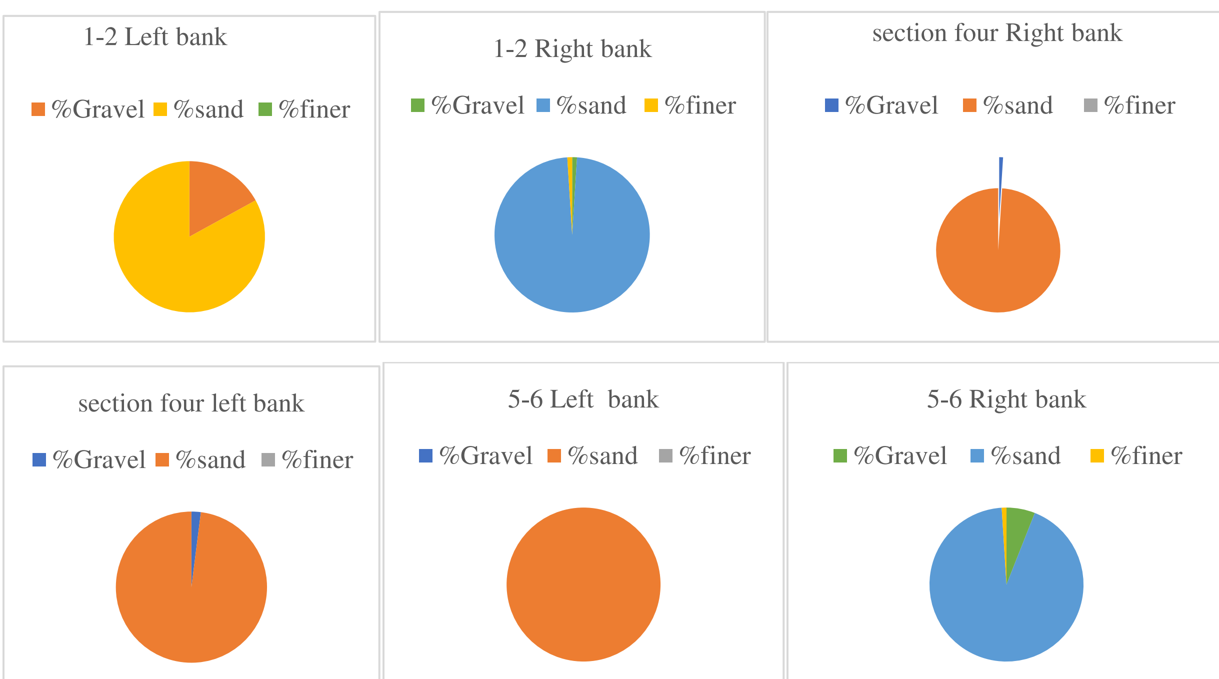
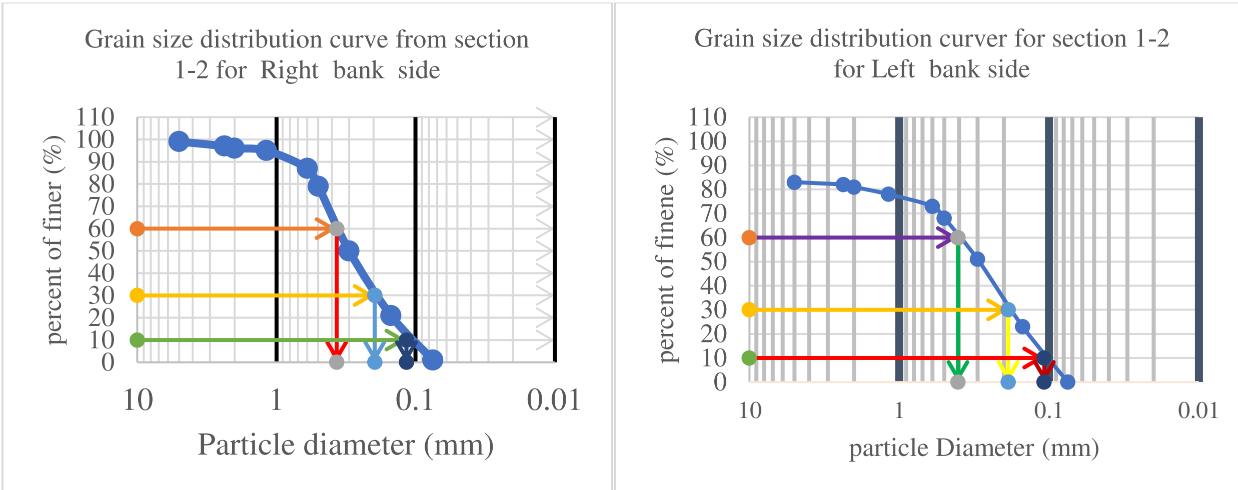
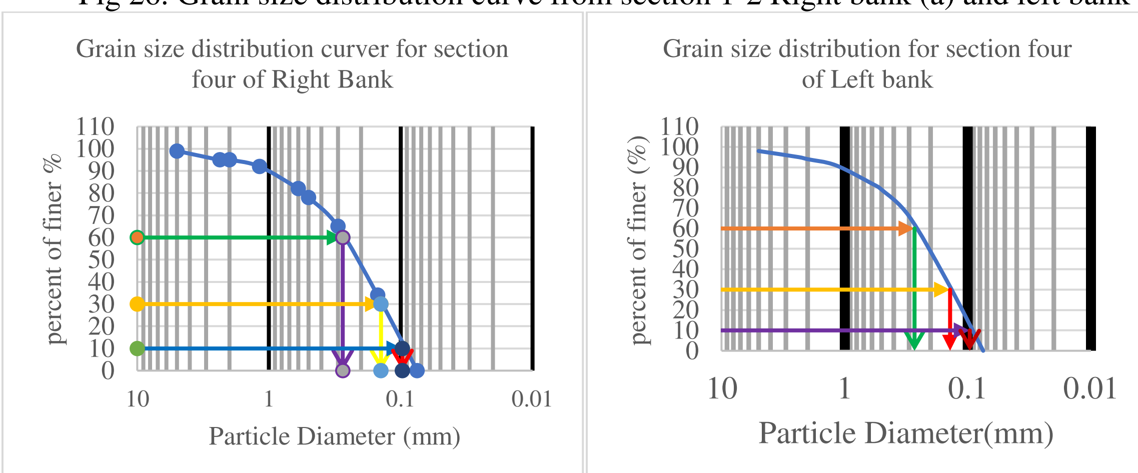


Fig 25. Percentage distribution of gravel, sand, and finer for the nominated section



a **b**

Fig 26. Grain size distribution curve from section 1-2 Right bank (a) and left bank (b)



a **b**

Fig 27. Grain size distribution curve for section four Right bank (a) and left bank (b)

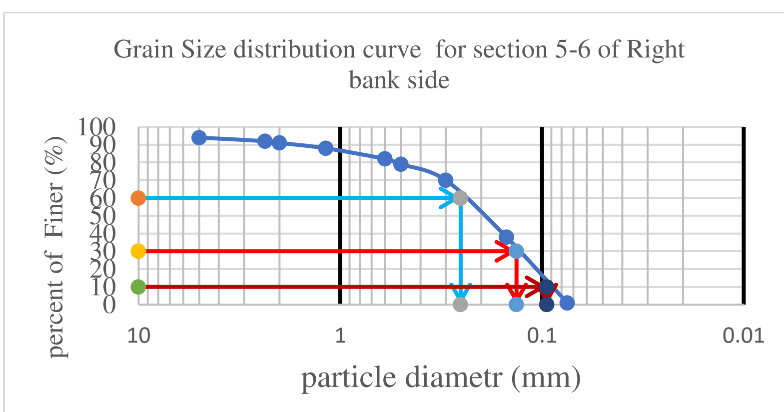


Fig 28. Grain Size distribution curve for section 5-6 Right bankside

3.3.2. Anthropogenic Drivers

Various hydraulic structure development around and on the river, sand mining, intense agricultural use within the watershed and around the river channel, and water extraction for irrigation during the winter season are all anthropogenic forces that cause the river plan to alter (Isik et al., 2008). Excessive water extraction using the pump during the winter, sand mining, intense agricultural operations, and incorrect river bank soil excavation for mud were highlighted as human activities for this study. This is because the fundamental drivers that damage the natural landscape are these individual activities, as well as the combination of each individual as a whole.

Fig 29. Sand mining site

3.3.3. water extraction

Water extraction was heavily practiced on both the left and right sides of the river bank in every segment of the study reach except section three. Intensive water extraction was used for irrigation in all section of the reach, and this unplanned water extraction entered the riverbank's cracks, causing the riverbank to become saturated and weaken, facilitating bank erosion and contributing sediment to the river. The anthropogenic driver for the upper reach of the Gumara river basin, including the river itself, increased with time on the watershed, which was confirmed during site observation and certain indigenous people's communication surrounding the study reach.

Fig. 30.Water extraction using pump

3.3.4. Current Status of the study reach

Throughout the site observation period, which lasted from January 22 to January 26, 2021, the research reach was carefully examined. The site observation reveals the status of both deposition and erosion processes, as well as the direction in which erosion and deposition were dominated. Sections one and two were dominated by erosion on the left side and deposition on the right. Because of the deposition in the Fogera weredas, people planted a variety of crops Fig (31) including tomato and maize, along the riverbank. Section three experienced minor erosion due to the fact that it has a relatively sturdy river bank and bed, is covered by sound rock material, and the erosion was caused by withering effect. Sections four, five, and six were eroded in both directions, with section five exhibiting significant erosion on the right bank and deposition on the left. Finally, section six is heavily eroded on the right side and deposited on the left, but the erosion exceeds the deposition.

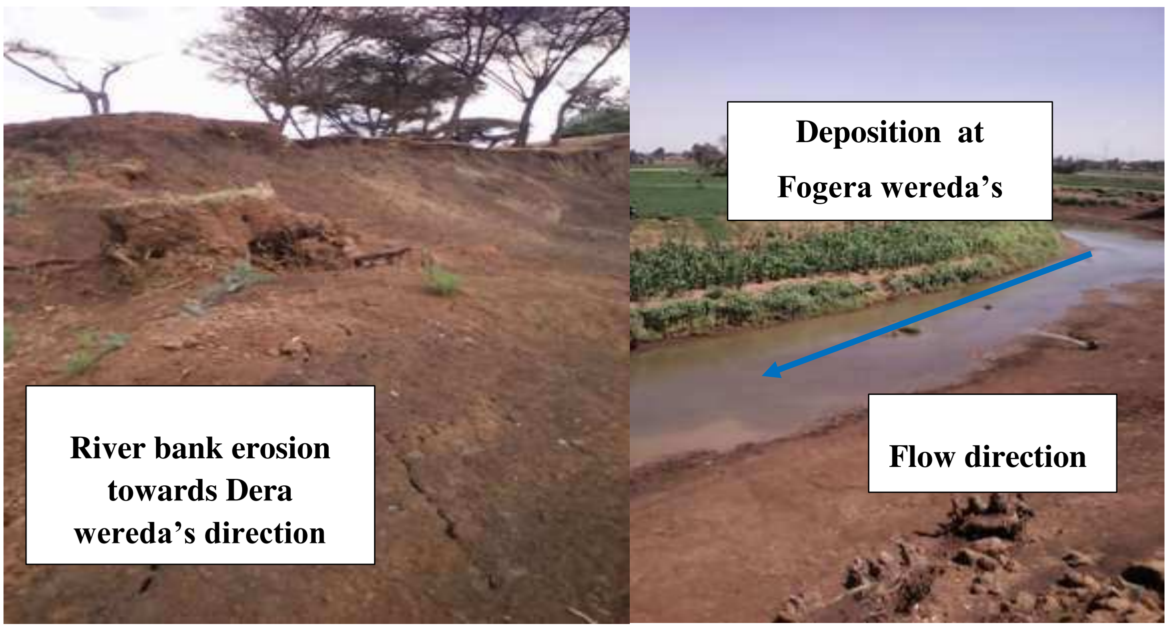


Fig 31. Erosion and deposition process in the upper reach Gumara River

Majetdfa village at Abagunda Kebele was one of the communities at risk due to the study reach's lateral migration, i.e., the village is 84.00 m away from being cut off due to riverbank migration, as shown in Fig (32).

Fig 32. Anthropogenic Activates in the study reach

Fig 33.Ways of bank erosion

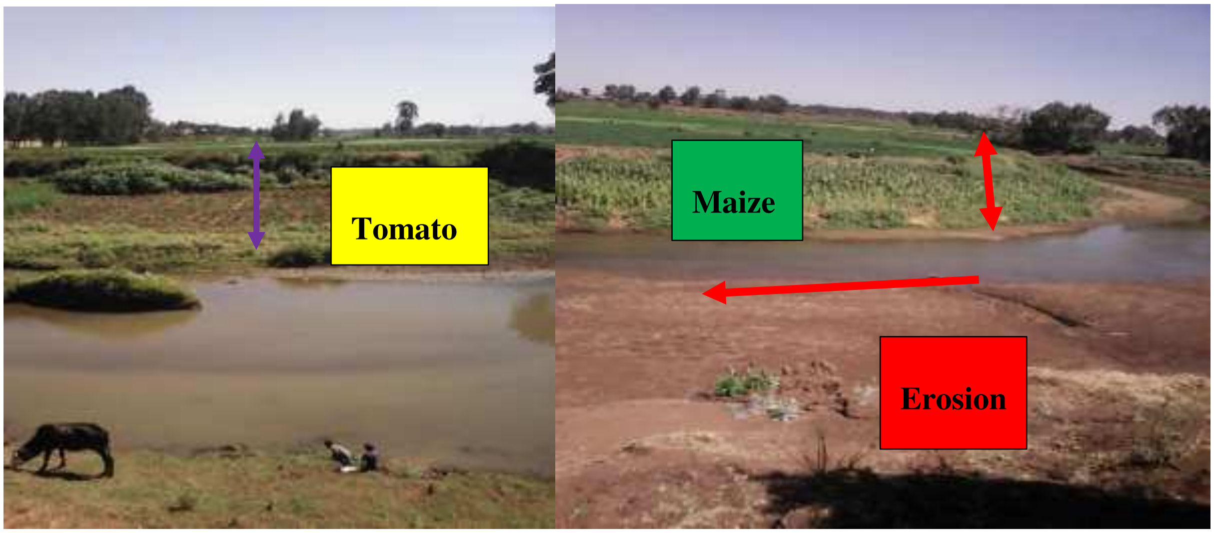


Fig 34. Tomato and maize harvesting practies within the study reach at deposition section

5. Conclusions

This research focused on investigating and analyzing the status of the upper reach Gumara river morphological chractrization and change utilizing GIS 10.5 and ERDAS Imagine 2015, as well as actually measuring, observing, and interviewing local indigenous peoples in the study reach. Various historical images, site observations, and restricted hydrological data such as rainfall, streamflow, and sediment concentration were studied to achieve the goal. The various indices used to measure the change reveal that the study reach was dynamically modified through time. The percentage change of average sinuosity from 1957 to 2020 was estimated to see how the general sinuosity of the upper reach Gumara River evolves over the research period. The calculated value was changed by 1.27 % from 1957 to 1999, 1.25 % from 1999 to 2006, 1.65 % from 2006 to 2013, and 1.22 % from 2013 to 2020, while the sinuosity index raised by 5.49 % during a 64-year period. The increasing order in the sinuosity index suggests that the river has become more meandering through time, increasing the likelihood of a neck cut and winding of the river bank. The braided index was also calculated at sections four and two of the study reach for the period 2006-2020, and this index increased over time, indicating that the river had split into two channels at that location. Totally the various used prametrs analysis result specifies that, the study reach was varied both temporally and spatially,and discharged irrversiable damage to the scio-economic system though out the reach. We documented both deposition and erosion of the river bank at various sections of the study reach based on site observations. Comparatively, erosion was greatly migrated toward the left or Dera weredas direction at sections one and two of the study reaches, and deposition was in the right sides of the Fogera weredas side, whereas section six had extreme erosion on the right side and deposition on the left side. Various mechanisms were employed to determine whether the drivers of change are natural or manmade effect in order to distinguish the drivers that regulate the plan from the dynamics of the study. Rainfall trend analysis, streamflow analysis, sediment load analysis, land use land cover change analysis, laboratory analysis on bank materials, site observation, and detection of human involvement were all carried out around the study reach. Sand mining, concentrated farming operations, water extraction by pump, and deforestation were observed among the numerous human interventions. Finally, the driver that controls the plan form dynamics was linked to both natural and anthropogenic factors. However, the primary driver was anthropogenic, owing to the fact that significantly human reactions were practiced within the watershed and on the river system itself, and most natural drivers, such as streamflow and sediment load, were stimulated as a result of anthropogenic activities. This transformation had an impact on a variety of agricultural goods, as well as the social and infrastructure systems, as evidenced by site observations and interviews with local indigenous people. For instance, this year's flood inundation of the Welale kebele, loss of agricultural land in each season, destruction of the water well at section one of the study reach, and Magetdfa village at Abagunda Keble were the finest examples. As a result, for each portion of the main reach and its tributaries, a social integrated management system should be established and implemented in order to restore the endangered section.

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Conflict of interest

We here submitted the manuscript "entitled Investigation and Analysis of Channel Plan Form Dynamics in Upper Reaches of Gumara River, Tana Basin, Ethiopia" to be considered for publication. We declare that this is our original research work. There is no conflict of interest between the authors.

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Ethical statement: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants involved in the study. I understand that journals may be available in both print and on the internet, and will be available to a broader audience through marketing channels and other third parties. Therefore, anyone can read material published in the Journal**.**

I signed on behalf of all the authors

Author name	Signature	date
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