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A Remote Sensing Technique to Understand River Channel Shifting of Narayani River †

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Abstract: Rivers are the dynamic water resources on the earth's surface. River morphology focuses on how water courses' shape and pathways change. This study focused on the Narayani River of central Nepal using remote sensing techniques to understand its dynamics. We used Landsat 5, Landsat 7, and Landsat 8 for river images from 1990, 2005, and 2020, respectively. Supervised classification of satellite images classified them into water and non-water bodies. We adopted two approaches to quantifying river shifting: linear displacement and the area change method. Interestingly, the watercourse of the Narayani River increased from 1990 to 2005, but it decreased sharply in 2020. The shifting of rivers was intense in the southern plain region compared to the northern slope region. The river width ranges from 44 to 511 meters. During three decades, the watercourse area was expanded by 14.09 sq. km and contracted by 15.11 sq. km at most within our study area. Monsoon rain leading to annual flooding is the primary cause for a change in water course. This research provides a vital baseline for supporting researchers and policymakers in strategic planning to keep the watercourse intact and prevent erosion from central Nepal.

Keywords: River shifting; Narayani; Remote Sensing; Landsat; Area Change

1. Introduction

River morphology is the science that focuses on the form or shape of a river across its length and cross-section. Rivers are likely to carry sediments during water flow. Erosion is the major cause of change in river dynamics because it leads to soil loss in an area and accumulates in other regions, known as accretion [1]. It has a combination of bank erosion and endpoint bar deposition over time. All the riverbeds change across the time interval, but some change quickly compared to others. River shifting results from various factors like fluid dynamics (velocity, discharge, shear stress), channel properties (slope of riverbed, water, pattern), sediment load (type of soil and its texture), and land use type (agricultural land, forest, bioengineering, embankment) [2]. All these factors are associated with river erosion, which is the cause of riverbank shifting. Thus, river channel shifting is a natural process, but anthropogenic activities accelerate it to a greater extent.

Usually, rivers are classified into two types: meandering and braiding. The meandering is the one that occurs mainly in the floodplain where channels move through the curved path. They erode the outside edge of the bank and deposit on the inner bank of the river. Their banks are mostly sand-filled, and water has a lower velocity. Eventually, with time, the river flows the shortest path instead of meandering, resulting in oxbow lakes. Braiding rivers are mostly on slope areas where water flow has higher velocity, and its bank usually has rocks and stones [3].

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A river is formed with water that moves from a higher to a lower elevation because of gravity. They usually join the more or less water bodies like ocean, lake, sea or another river. They have a deeper depth in the center and symmetrically decrease on both sides of the banks [4]. The rivers in Nepal originate in mountains, which flow after the snow melts, travel a range from mountains to flat Terai, pass the national boundary to India, and eventually meet the Indian Ocean. As in the mountains, they have high velocity and more eroding strength but lessen their eroding power as it comes down to flat lands and cause siltation [1]. Usually, the river channel changes because of bank erosion, down cutting, and bank accretion, which human activities may influence [5].

Deposition of sediments, debris, or materials swept away by river flow usually happens in the lower flat plains. The upper stream faces erosion, and the downstream faces sedimentation. Another way of deposition is anabranching, which has a multiple flow path, thus making it capable of carrying sediment load from different trajectories [6].

The application of remote sensing to understand the evolution of river channels across multiple time frames is becoming popular as it can act as a basis for understanding the dynamics of river courses [2]. The availability of data from different platforms with spatial, temporal, and radiometric resolution variations makes it a reliable approach to explore river dynamics. Two methods are mostly adopted to quantify river shifting. The first is by a linear river shifting during a time interval [7]. Another way of doing it is a temporal position of the river channel using a remote sensing dataset and comparing it with ground conditions [8]. Geomorphology, water velocity, land use pattern, vegetation types, and discharge amount need to be accounted for river shifting.

The river channel, or course, helps us understand the river's pathway. The size and shape of the river influence the deposition and erosion process occurring on the riverbank and the formation of bank platforms. The cross-section of the river is the profile of the river perpendicular to the flow direction, which helps in flood mapping. In contrast, the platforms help understand the sedimentation and deposition in the flood plains [9]. Hence, understanding the river channel shifting helps analyze river cross sections and platforms.

We investigated the shifting of the Narayani riverbed in three decades. Remote sensing is the best approach to study this kind of temporal change in the earth's surface, where the present status of river channels can be compared with the past. It gives a base of understanding how water courses are shifting, which direction, and the area of surface water change, which has practical implications for managing this water source for humans and wildlife in the area for the long run.

2. Materials and Method

2.1. Study Area

Nepal lies in Southeast Asia with an area of 1,47,181 square kilometers, rich in natural resources and physiographic diversity. The country has an elevation changing from 8,848 meters to 60 meters within 300 kilometers. Thus, the country is rich in biodiversity with variations in altitude and climatic conditions. There are three major river basins in Nepal: Koshi in the east, Gandaki in the center, and Karnali in western Nepal. Narayani River, the border to Chitwan and Nawalparasi districts, is part of the Gandaki River basin in central Nepal. Further, this river is well known for its deepest gorge upstream in hilly regions. We took a segment of the Narayani River from Devghat (latitude: 27.74 longitude: 84.42) to Gholaghat (latitude: 27.56 and longitude: 84.15). This segment flows from north to south and covers a diverse segment from foothills, urban areas, and protected forest areas, giving insight into conditions across various slope and land use scenarios. Narayani River has an average annual water discharge of 4500 to 7500 m3/sec, excluding heavy flood scenarios [10]. Similarly, the temperature ranges between 9-36^{0} Celsius in this area.

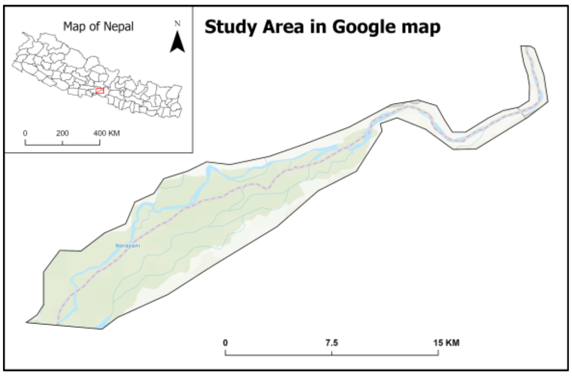


Figure 1. Study Area Map of Narayani River.

2.2. Data Sources

We obtained cloud-free images from the USGS website. The Landsat images obtained were georeferenced and projected to the UTM Zone 45 N projection and WGS 84 datum. The details of the images are given below:

Table 1. Data specification.

Dataset	Platform	Path/Row	Resolution	Year
Landsat TM	Landsat 5	141/41 141/42	30 meters	1990
Landsat MSS	Landsat 7	141/41 141/42	30 meters	2005
Landsat OLI	Landsat 8	141/41 141/42	30 meters	2020

The standard false color composite images of Landsat for the years 1990, 2005, and 2020 are shown below:

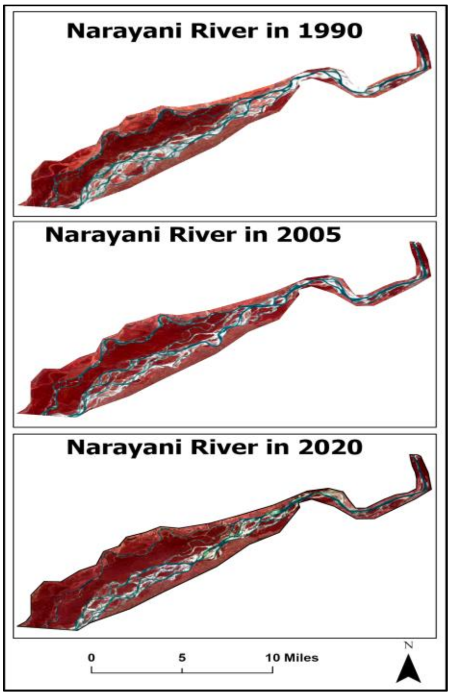


Figure 2. Standard False Color Image Narayani River across the years.

2.3. Data Analysis

Data analysis for this study begins with the supervised classification of the study area. We converted the satellite images into binary images of water and non-water areas. This study adopts two approaches to understanding the change in the watercourse of rivers from the years 1990-2005 and 2005-2020. First, we used image difference to investigate water course area change for two 15-year intervals. It gives the idea of how much area of surface water changed during this period. Second, an investigation was done into the river's width change. First, we bisected the river for 2020 with an imaginary straight line along the river's length. After that, we choose a point every 5 kilometers to collect the data from those sample points. A perpendicular line was drawn as a transect across the river's cross-section from those points. The raster was converted to a vector file to measure the river width precisely. We measured the river's width across those transect lines and recorded the values.

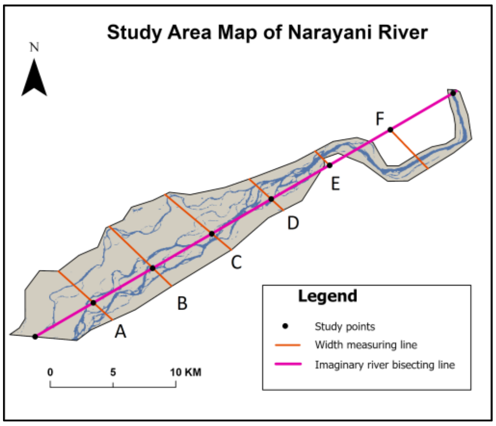


Figure 3. Study area showing lines for river width measurement.

3. Results

Here, we can see the classified images of the river and land area for the Narayani River in 1995, 2005, and 2020 with overall accuracy of 84.4%, 80.2%, and 82.3%, respectively. Similarly, the kappa-coefficient of 0.69, 0.61, and 0.63 was reported for those years. Visually, the water area increased in 2005 compared to 1990 and later decreased in 2020.

Moreover, we can see more river tributaries of the Narayani River in 2005 compared to 1990. The water course is larger, and smaller tributaries are distinct and continuously detected in satellite images in 2005 compared to 1990 or 2020. It clearly explains that the water discharge in Narayani was higher in 2005 than any other date.

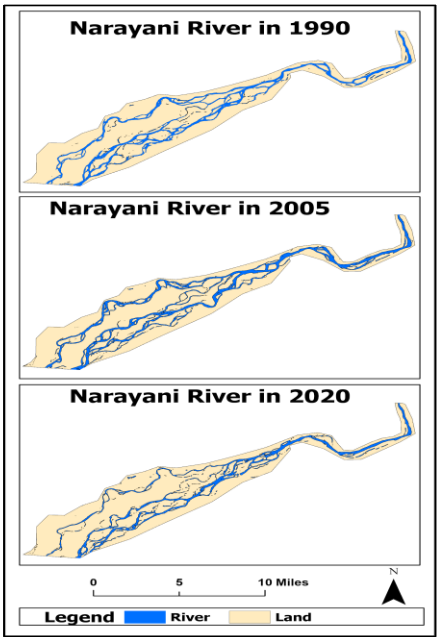


Figure 4. Narayani River water course in different years.

We classified the raster to binary as river and non-river area. After this, we used a raster calculator and deducted the 1990 river map from 2005 and the 2005 river map from the 2020 river map. So, the final output map gave three values: 0 for the unchanged river area, 1 for the increased river area, and -1 for the decreased river area.

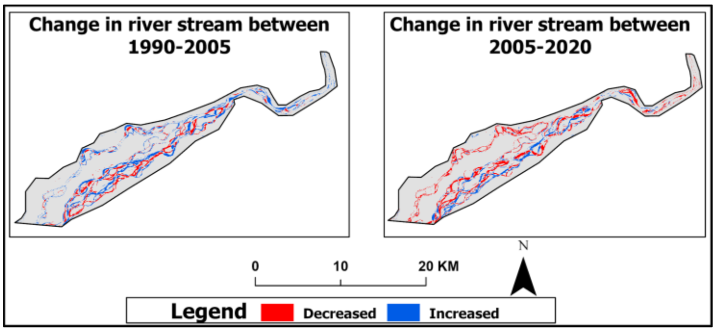


Figure 5. Change in river course during different time periods.

After the conversion of raster to vector, the area of the river course can be calculated each year. From 1990-2005, the 8.48 sq. km area of the river course decreased but increased by 14.09 sq. km. Similarly, in the period of 2005-2020, 15.11 sq. km decreased but increased by 8.2 sq. km. Thus, the river increased in 2005 compared to 1990, but the same water course decreased more than the level of 1990 in 2020.

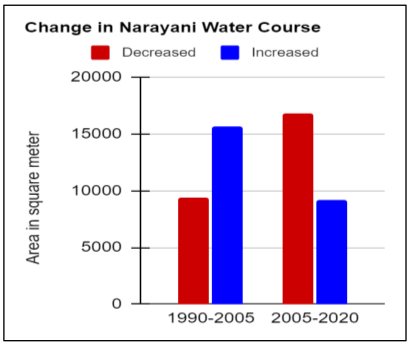
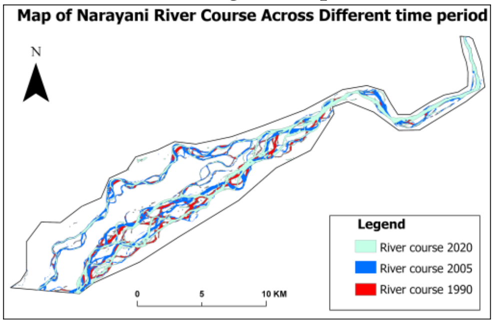
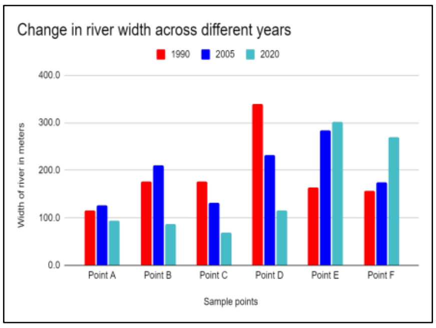


Figure 6. Bar graph showing the watercourse area change during two time intervals.

To understand the change in river width, data collection stations are kept at an interval of 5 kilometers after bisecting the river. Another line was drawn from each point station that is perpendicular to river bisecting line, so river width can be measured and compared across those line points. We have 6 points, excluding the first one on each end. The width was measured from one edge to another on the perpendicular line. As rivers could have fewer/more branches, we measured all the branches along the line and averaged them to get comparable river width across each data collection station.



(**a**)



(**b**)

Figure 7. (a) Superimposed map of Narayani; (**b**) Width at sample points.

From the bar graph, we can see the river's width on the left for points A, B, C, and D are higher for 2005, followed by 1995 and 2020. River widths are extended at points E and F in later dates compared to the past.

Further, we can see that the watercourse has shifted back and forth across this time period (Figure 7). From 1990-2005, it moved towards the south, as shown in red and blue, but in 2020, the water course shifted to the north in the left region, as shown in cyan color.

4. Discussion

Nepal lies in a sub-tropical climate that receives nearly 80% of rain during the monsoon season, i.e., May-June-July [11]. This is when all the catchments receive more rainfall, and rivers have increased discharge. The river gets an increased volume of water, and its velocity increases. The river course with a meandering flow path aims to surpass the bank on roundabouts and follow a straight path, resulting in the river's shifting. This is the prime reason for the change in the river course.

There might be several reasons behind the increase in the watercourse area in the 15 years from 1990 to 2005. [12, 13] reported deforestation as the reason for river width increment due to the increase in run-off because it does not have any vegetation to intercept water or organic matter-rich soil, which can hold more water. Another reason might be climate change-induced melting of ice and an increase in water discharge [14] in the mountainous part of Nepal, which causes an increase in the volume of water at the upstream level and deposition downstream. Urbanization through deforestation could be another significant reason for urban flooding. It led to an increase in the river course from 1995 to 2005, as that period was the transition phase for Nepalese from the mountains to Terai for better education, health, and living [15]. Extending the watercourse in points E and F (Figure 3) closer to an urban area further bolsters this reasoning because the urban area restricts water percolation on the ground and increases surface flow directed towards the river.

In contrast, the river course decreased more during 2005-2020 compared to how much it increased during 1990-2005. Scouring resulted in a decrease in river's width over time in Italy, as per a study by [16]. The increase in river depth due to the scouring process can be prevalent in our study area. With time, the rise in water flow can lead to more erosion in the riverbed, resulting in scouring of the water course, so the surface area appears shrunk when the volume of water is the same. [17] found climate change results in decreased river water discharge in Australia. In the case of Nepal, it could be related more to the decrease in snowfall in the Himalayas region with increasing mean temperature [18, 19]. So, decreased snowfall will not result in more water discharge, even though climate change leads to more ice and snow melting. Hence, this indicates that the Narayani River's small discharges may be related to a lower amount of snowfall and glaciation in high altitudes, resulting in a surface area shrinkage in the latest date compared to previous years.

4. Conclusions

This study integrated remote sensing for long-term river channel monitoring, crucial for dynamic rivers prone to yearly floods and course changes, leading to the creation of oxbow lakes. Examining the Narayani River from 1990 to 2020 reveals fluctuations in the watercourse, indicating erosion and siltation significance. Effective river monitoring is essential for minimizing impacts on land use and communities. Additionally, it identifies flood-prone areas, aiding in embankment planning. Furthermore, this research serves as a baseline for quantifying annual water discharge and soil erosion, assisting planners and policymakers in addressing changing river conditions and potential issues.

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Appendixes

Table A1. Confusion matrix for 1990 map.

	Water	**Non-water**
Water	38	11
Non-water	4	43
Overall Accuracy	84.4	
Kappa coefficient	0.68	

Table A2. Confusion matrix for 2005 map.

	Water	**Non-water**
Water	39	16
Non-water	3	38
Overall Accuracy	80.2	
Kappa coefficient	0.61	

Table A3. Confusion matrix for 2020 map.

	Water	**Non-water**
Water	35	10
Non-water	7	44
Overall Accuracy	82.3	
Kappa coefficient	0.63	