Geoinformatics Based Modelling of Channel Planform Dynamics for River Ramganga

रामगंगा नदी के लिये जियोइन्फोर्मेटिक्स पर आधारित चैनल प्लैनफॉर्म डायनेमिक्स की मॉडलिंग

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8.1 Introduction

The present study has been carried out to determine how and to what extent planform changes have taken place in the high dynamics rivers and how it can be predicted using Geoinformatics based modelling techniques.

Remote sensing data, historical topographic maps, hydrological data, elevation data and soil data were the main inputs in the present research. The availability of these data has opened up a new opportunity to model the high dynamics river systems of the world. The information extracted from the remote sensing data and hydrological data was used to infer the morphological processes occurring in the Ramganga river which has resulted in a reconstruction of the planform dynamics from historical times to the present time.

The present research showed that spatial data could be efficiently utilised to understand the evolution of the highly dynamics Himalayan rivers. This study is able to understand the basic evolutionary mechanism of the channel planform dynamics of Ramganga and explain the morphological process of the river enabling better management of the river system. The study also established the possible causes of the avulsion of the Ramganga river from the old channel to the new channel. The overall research evolved around four research objectives to achieve the aim of this study "Geoinformatics based Modelling of Channel Planform Dynamics for River Ramganga". The following sections summarise the major findings associated with all objectives. This enables us to draw conclusions of this research and answer the research questions as outline in Chapter 1.

8.2 Specific conclusion

The specific conclusions have been summarized based on the individual chapters of the thesis:

8.2.1 Chapter 4

In chapter 4, the Landsat archive and historical topographic maps are used in a GIS platform to understandthe channel planform dynamics of Ramganga river over ~237 years.

The lower reaches of the Ramganga display major changes in planform. The Ramganga river is a highly meandering river which shows the sinuosity index more the 1.5. In section A, the Ramganga is displaying meandering nature at all sections. The overall shifting of the Ramganga river is towards the south-west direction, which follows the regional slope towards the Ganga river. The variation of the channel planform is very high from 1780 to 2017 and observed ~ 8 km shifting near the confluence of Ramganga and Baghul river. The village Garhi Aurangabad and Kundauli have been completely eroded due to westward shifting of the channel from 1780 to 1923.The confluence shifted 10.58 km toward the west from 1780 to 2017. It shows a highly dynamic nature of confluence of Ganga and Ramganga rivers. In section B show the large-scale dynamics of planform in which a major avulsion of ~8 Km is observed in which river left its old course (Ghambhiri river) and occupied a new channel (Kunda Nala).

Floodplain topography has played a major role in shifting of the river course. Topographic maps and satellite imageries were used to study the river courses during the study period (1780-2017). In the first segment of lower Ramganga, the general movement of shifting is towards the southwest. The planform dynamics of the Ramganga river has been controlled by two mechanisms (a) meander migration of sinuous channels and (b) low slope toward the southwest direction in the downstream channel. It is observed that the lower Ramganga river is highly dynamic except for the ~8 Km reaches between the village Bari (B) and Mastapur (M) which is highly stable and suitable for construction of bridge structure.

This analysis is helpful to understand the channel planform dynamics of lower Ramganga river, and it is also important to understand that channel planform dynamics is a natural behaviour of the alluvial rivers. This study will work as a decision support system for local planners and decision-makers for river management activities. Specifically, local concerns over the potential lateral migration of the river Ramganga and consequent erosion and loss of productive agricultural land. It is essential to map the planform dynamics through remote sensing and GIS to save the large population from flood hazards and erosion through river dynamics, and it may also play an essential role for improving the health of Ramganga river.

8.2.2 Chapter 5

Chapter five discussed the impact of monsoonal rainfall on the Ramganga river morphology using SAR data. Monsoon is the main cause of flood in Himalayan rivers.Therefore, most of the alluvial rivers carry out almost all geomorphic work (erosion, transportation and deposition) during the monsoon season. Obtaining spatial information over a large area using optical remote sensing is not possible due to cloud cover during the monsoon period. Microwave remote sensing can penetrate the cloud cover and collect the data during the monsoon period. So the monitoring of river planform is only possible using microwave remote sensing data during the monsoon season.

Sentinel-2 has a very high temporal resolution of 12 days which enable to map the real-time flood inundation in the Ramganga river. The multiple images of the study region have enabled the advancement and retreat of floodwater from 09 August 2018 to 23 September 2018.The daily water level data from the Dabri gauge station shows that Ramganga River water level starts rising from 5 August 2018 and reached two consecutive peaks between 9 and 18 August 2018.The worst condition of flood occurs on 25 August because of the enormous amount of water has discharged in the Ganga and Ramganga riverwhich seriously affected the morphology of the river. These rivers started to flow above the danger level, which increased the flooded area by 25%. It has been reached about 45 % on the 30 August,and 2 September, 2018, which was the highest flood area covered in these periods, which is devastating.

The remote sensing and hydrological data reveal that the flood condition was very disastrous in the studied area from 28 August to 8 September, which seriously affected the channel planform. This extreme flood leads to a change in the morphology of the rivers and its floodplain. Results display that the flood significantly altered the bank conditions, channel width, and sinuosity. The pre and post-flood event shows an increase in active channel width from 86.47m to 376.56m. The average sinuosity index decreased from 1.82 to 1.75 in post-flood periods. The principal effect is a high mobilisation of channel sediments, and severe bank erosion in the river reaches is observed. The massive erosion (337.16 ha) is observed in reach-5 near the meander bend due to the low slope towards the southwest direction. Maximum average widening occurs (~ 568.79 m) in reach- 8, whereas minimum widening occurs (~ 250) in reach- 4 after the flood. On the other hand minimum width was ~ 74 m in reach-1 and ~ 105m in reach- 8. A total area of ~1650 ha is eroded during the flood and deposition of ~8.5 ha took place. The maximum value (37.93) of RNCI is observed in the reach-5, and minimum value (15.81) observed in the reach-4. Highest sinuosity is found in the reach-5 due to its meander nature of the pattern, and it is increased from 3.08 to 3.21.

Understanding the morphological characteristics of a Ramganga river in reaction to the extreme flood is essential to forecast its impact on the engineering structure, e.g. bridges, railways, roads, embankments, settlement etc. Physically-based modelling also involve the morphological data for forecasting the channel behaviour during the flood.

Furthermore, a conclusion can be drawn that there were no gauge stationsdownstream of Ramganga to measure actual water level for the flood-affected area. In such a case,microwave remote sensing helps to evaluate flood-affected areas and supporting relief decisions during flood disasters.

8.2.3 Chapter 6

Chapter six investigated the evolution of the Ramganga river using remote sensing dataand the hydrological data from 1973 to 2019. The results showed that the study reach of the Ramganga river has significantly changed in the past ~46 years. In this period, six new meanders and 11 cutoffs were formed. The average width of the active channel narrowed significantly by ~43% along the river between 1973 and 2019.Meander (no. 12), which is near to the Baran village is very dynamic due to the erosional process of the river. Trends in the radius of curvature (Rc) of this meander has appeared unidirectional. A reduction in Rc initially observed from 1973 to 2019. In this meander, the overall reduction in the radius of curvature is 350m is perceived. This reduction in Rc shows the potential site of the meander cut off in the near future, which will eventually reduce the valley length of the river. The channel migration rate is also calculated in the decadal scale. The general trend of the rate of migration is reduced from 55 m/y to 22 m/y in the study period (1973-1981). The average migration rate is observed ~33 m/y in the study area.

The relationship between the frequency of flood and morphological changes is also analysed in this chapter. Our findings show that the flood frequency of Q_2 and Q_5 have seriously impacted the channel planform. The results of Pearson correlation test shows that the frequency of hydrological events Q_2 and Q_5 are directly correlated with the sinuosity index (0.74 for Q_2 and 0.83 for Q_5) and radius of curvature (0.78 for Q_2 and 0.65 for Q_5). The Channel migration and bank retreat in the study reach have a significant positive correlation with the frequency of floods 0.76 for Q_2 and 0.89 for Q_5.The channel width shows the very less correlation with flood frequency, and the test of significant value is high at 5% significant level, which indicates the width has some other reason of narrowing the channel planform. This reason could be the human intervention (diversion of flow,changing river morphology, sedimentation process stream). The radius of curvature shows a positive correlation with the flood frequency of Q_2 and Q_5.The test of significance also indicates that the radius of curvature of a meander is depended upon the flood frequency.

Hydrological events with different return periods play an important role in the morphological evolution of the Ramganga river. Cutoffs and higher migration rates are dependent on extreme and larger discharge events, while progressive bend development takes place during periods dominated by smaller flood events. The findings of this study could help understand the evolution of dynamic fluvial systems, particularly where flooding regimes are predictable in the monsoonal climate.

8.2.4 Chapter 7

The objective of this chapter is to develop a physically-based predictive model for modelling channel planform dynamics in a GIS environment for the next 100 years. This study investigated the Ramganga river morphology through RVR Meander model. This model is run for two different scenarios (1) natural meandering in present hydrological condition from 2020 to 2120 (2) impact of climate change through increased river discharge, and also to understand the (3) effect of channel planform dynamics on the surrounding settlement.

The Ramganga river has been an actively meandering river historically and will continue to bean actively meandering river in the future also. It is important to note that different meanders migrate at various rates depending on several physical factors, e.g., discharge rate, channel slope, river cross-sectional properties etc.

The channel shifting is observed in both side of the floodplain, and the maximum shifting of (~3 km) the channel may take place near the village Baran, whereas the lowest shifting of the channel centerline may take place in the stable reach which may be ~0.4 km. The modelling results strongly negates the earlier belief that the Ramganga river will avulse to the Sota nala in future. Now it is expected that instead of this avulsion here Baran meander neck cutoff may take place in next 30 years. This neck cutoff will reduce the river length by ~ 8Km, and the morphology will be drastically changed in this section of the river. The results of the model showed that the Ramganga bridge does not currently appear to be impacted by the migration of the Ramganga river in the next 100 years. The modelling results also show that in the near future the confluence point of Ganga and Ramganga river may shift to the upstream 5km in the upstream direction in Ganga river.

In the second model scenario, the calibrated model was again run for 100 years with a 50% larger bankfull flow value. The results show that the maximum shifting of the channel may take place near the village Baran which may be ~3.5 km, whereas the lowest shifting of the channel centerline may take place in the stable reach which is ~1 km. The Baran cutoff may take place in next ~20 years in the high flow condition. This neck cutoff will change the morphology in the downstream area. So, the village Baran and Mastapur village are on high risk of erosion due to this neck cutoff. Just downstream of the Ramganga bridge, the model predicts that the channel migrates approximately ~ 6 km toward upstream the Ganga side over the next 100 years which may become the site for the confluence of Ganga and Ramganga rivers. Overall, the model predicts that the Ramganga Bridge will not be greatly impacted by the migration of the Ramganga river for the next 100 years. This meander erosion requires the monitoring of morphology of the Ramganga river for the long life of the bridge structure.

In the third case, it is observed that extensive erosion will take place along the study reach in the next 100 years. Along the Ramganga, many villages are historically eroded, which are now uninhabited, and in coming future, there may be ~48 villages which are highly prone to erosion. Destruction of surrounding infrastructure like farmer's houses, agricultural land, and civil infrastructure can directly endanger the lives of the local inhabitant during the river erosion. The flood protection works are required in this region to protect these settlements along the river.

8.3 Limitation of the research

The first limitation of the research is the available gap in spatial data, especially in the period of 1780-1923 and 1923-1973. A generalisation of the river planform had to be accepted in interpreting the channel planform dynamics in these time periods. Some further investigation would have been possible if the data gaps could have been filled up.

There are some limitations present in the RVR Meander model also. First, it is the two-dimensional model which is a simplified version of three-dimensional reality. It used constant water supply throughout the year, butthe Indian river fallows the monsoonal pattern of river regime, which is not constant throughout the year. Further, in this model,river bed aggradation or degradation is not utilised, which is a major factor of the river morphology development. This model also uses the constant channel width throughout the channel, which is not found constant in naturally meandering rivers. However, this physically-based method for bank erosion is much advanced over the migration coefficient model but still does not completely capture all of the physical process involved in bank erosion. Additionally, this version of the RVR meander model cannot model the cutoff processes like neck cutoffs but still can be predicted by visual interpretation of migrated centerlines.Further, in this model, the soil properties were considered to be a homogeneous layer, but in reality, there are different types of soil texture foundduring the field survey which have an impact on channel planform dynamics.

Finally, this model is based on the physical parameter for the Ramganga river e,g, river width, erosion rate coefficient, model discharge etc. Any anthropogenic or natural perturbation may change the results of the model. For example, the frequency and timing of major flood events, streambank modification, river training works, or an unexpected local change in soil properties could alter the result of the proposed model.

8.4 Scope for future research

The present research works reveal that the channel planform dynamics of a highly dynamic river like the Ramganga system could be modelled using Geoinformatics based tools and techniques. Thedynamic rivers can be interpreted from various river metrics extracted from the spatial database supported by hydrological and soil data. The physically-based modelling approach can explain the morphological changes that have occurred in the fluvial system and future scenario for a long period of time. Based on the findings, the present research has enormous scope for further investigation. This research may be carried forward in the following directions in future.

The first area is to explore the additional control variables which can be added to the empirical model in order to increase its explanatory power of the model. One such potential variable could be the effect of the vegetation on the channel planform dynamics. Vegetation has a complex relationship with channel planform dynamics. It has some influence on flow characteristics and physical resistance of bank material, so this is an important parameter to be included in the physically-based model.

Another area for future study would be the prediction of bankfull discharge based on the climatological data. The frequency of these events seems to be correlated with the frequency and magnitude of monsoon. All the geomorphic work is highly correlated with the monsoonal rainfall. Therefore, the use of monsoonal rainfall data may provide a control variable for model development.

The third area for further study would be to explore the human intervention on channel planform dynamics. The hydrological and morphological characteristics of the Ramganga rivers have been intensively modified by human interventions. Anthropogenic activities such as land use transformation, construction of dams, embanking, in-channel sand mining and construction of bridges over the river channels also affect the channel planform dynamics.

Lastly, this physically-based predictive model should be tested for other dynamic rivers around the Globe. This would enable broader generalizations to predict the channel planform dynamics.