Chapter-2

LITERATURE REVIEW

Chapter 2

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2.1 Introduction

Alluvial rivers are highly dynamic morphological system in nature which has great socio-economic, cultural, and political importance. Channel Planform dynamics of these alluvial rivers are a very complicated process and which differ spatially and temporally from one river basin to another. These rivers regulate their morphology-based on variation in spatial and temporal variables (e.g. sediment load, channel morphology, discharge, and bank material properties) [21]. The channel planform dynamics of the alluvial river are usually done through active lateral erosion of flood plain. The rivers display dynamic behaviour by shifting their course from an existing channel to a new channel, fully or partially depending on flow dynamics and sediment transport characteristics of the channel. The process by which rivers demonstrate such a shifting behaviour spatially is known as river avulsion[21, 22]. Channel planform dynamics of river systems give rise to various morphological forms and patterns in the floodplain, which can be broadly classified into straight, meandering and braided [24]. However, new or transitional or higher-order channel patterns have also been identified [24, 25].

As a part of this study on Geoinformatics based modelling of channel planform dynamics of the Ramganga river, a review of remote sensing and GIS (Geographic Information System) based modelling of the fluvial environment is presented in the following section.

2.2 Channel pattern

Channel planform is an essential feature which plays a vital role in the study of river morphology. It is the planimetric geometry of an alluvial channel, as seen in the maps/ satellite image[8]. Channel Planform/river pattern is created by feedback between streams, floodplain, bars and vegetation, which is controlled by the spatial sorting of bedload and wash load sediments. The channel width and pattern is determined by the balance between floodplain formation and destruction [27]. This channel planform configuration gives shapes to different channel patterns.

2.3 Channel pattern controls

Alabyan and Chalov, (1998) studies the types of river channel patterns and their natural controls and find out one of the most important factors in channel development is stream power, defined by water discharge and river slope [28]. Li et al., (2013) analyse the channel pattern controls upon in the upper yellow river, qinghai-tibet plateau. Remote sensing images, DEM data and field investigations are used to understand the channel pattern control on the river planform. The major channel pattern controls are found the channelslope and bed sediment size, which are key determinants of transitions in channel planform[29]. Yu et al., (2014) Guo-an Yu 2014 studies channel planform controls in the source region of the Yangtze and Yellow Rivers and finds out that theregional gradient of variation in riparian vegetation and interactions between vegetation development andhydrologic process are the major factors influencing this difference in channel planforms[30]. Bawa et al., (2014) studies the natural and anthropogenic controls on the morphological variability for the Yamuna River, India. This studies find out the stream power and sediment load data are the major control variable which controls the channel morphology[31].

River systems adjust by a group of controls which gives rise to the evolution of various channel planforms resulting in the evolution of floodplain morphology [32]. A brief discussion on the various controls of channel planform is described below.

River channels have been classified in fluvial geomorphology as straight, meandering and braided, which represent a continuum of channel geometry in the fluvial environment [24]. The channel planform evolution is primarily dependent on the force exerted by the river flow on the river banks and the resistance exerted by the river bank material to counter the erosion mechanism. This equilibrium is controlled by some independent variables like bed material size, slope, sediment load, discharge, bank composition and strength [33].In the beginning, numerous empirical relationships were established to explain the straight, meandering and braided channel pattern based on some of the controlling variables.

The subsequent classification was based on channel slope and bankfull discharge which is calculated based on the following equation

$$S_b = 0.013\, Q_b^{-0.44} \tag{2.1}$$

Where, S_b is channel slope and Q_b is bankfull discharge.

In this seminal work, this equation differentiates the fields corresponding to straight, meandering or reaches on a graph of discharge versus slope. Thus a threshold slope exists above which the channel would experience braiding of the channel. Numerous equations subsequently have been developed which differentiated between straight, meandering or braiding patterns using other parameters of the river. Channel pattern also classified on the bases of channel slope, discharge and the silt-clay contents of the river banks [34].

$$S = 0.0013Q^{-0.24}B^{1.00} \tag{2.2}$$

Here, S is the channel slope, Q is discharge and B is the silt-clay content of the banks. Gradients that are steeper than those predicted by this equation will induce braiding. Similar other equations also exist using other parameters of the river such as slope, discharge and median bed material diameter [34].

Thus, it can be said that the channel pattern mainly depends on two major factors a) flow strength and b) sediment characteristics [25, 29]. Rational regime based models have been recognized that strength bank material is an essential factor to understand river morphology and its behaviour [35]. But these models have their limitations if tested on real-world systems due to restrictions on the time scale of change and low discharge fluctuation, which is not always the case in the real world.

In addition, bank stability is an important parameter where shear stress exerted on the river bank must be equal to critical shear stress for bank erosion which is rarely found in natural river systems. The channel cross-section properties (which is in most natural systems would be asymmetrical instead of trapezoidal shape) employed in the modelling processes and the formulation of river bed material transport which would display non-equilibrium spatial and temporal variation in a natural river system. Flow resistant is difficult to predict using resistant equations of the regime model, which is evolving due to channel sinuosity, bars and other bedforms present in natural alluvial channels. Mostly these factors are responsible for up to 90% of the total flow resistance at bankfull discharge conditions and play an essential role in the channel pattern development[31,32].

The Flume experiments demonstrate the effect of vegetation on channel morphology which is conducted in the laboratory to understand the interactions among vegetation, sediment, and water in natural rivers [38]. The laboratory experiment demonstrated that riparian vegetation in the floodplain could lead to the self-organisation of braided channels to form a single thread channel which then maintains itself in a dynamic equilibrium [38]. The experiments results showed that riparian vegetation discouraged the coexistence of multiple channels and slowed down the rate of bank erosion.It allows deposition along the point bar with erosion along the outer bend, resulting in active channel migration while maintaining a constant width.

Land-use dynamics change the water and sediment supplied to rivers channel, which modifies rivermorphology toward a shape, which is capable of passing the supplied sediment with the available water in the channel. Changes in the supply of water and sediment can result from a wide variety of land uses sources like agriculture [39], mining operations[35, 36], urbanization [42], timber harvesting [43] or mixtures of different land uses[44].

2.4 River metrics

To study channel planform dynamics of a river, it is necessary to discuss a set of river metrics to obtain a perceptionabout the river morphology and the underlying processes that are active in the fluvial system.

The comparison of various river metrics is discussed below.

2.4.1 Sinuosity

The sinuosity of a river is one of the essential characteristics of a river channel pattern. The ratio of the curvilinear length to the straight (shortest) length between the endpoints of the river is known as the sinuosity index. Sinuosity is used as an indicator of channel behaviour, which determines whether a channel is straight or meandering (Fig. 2.1).

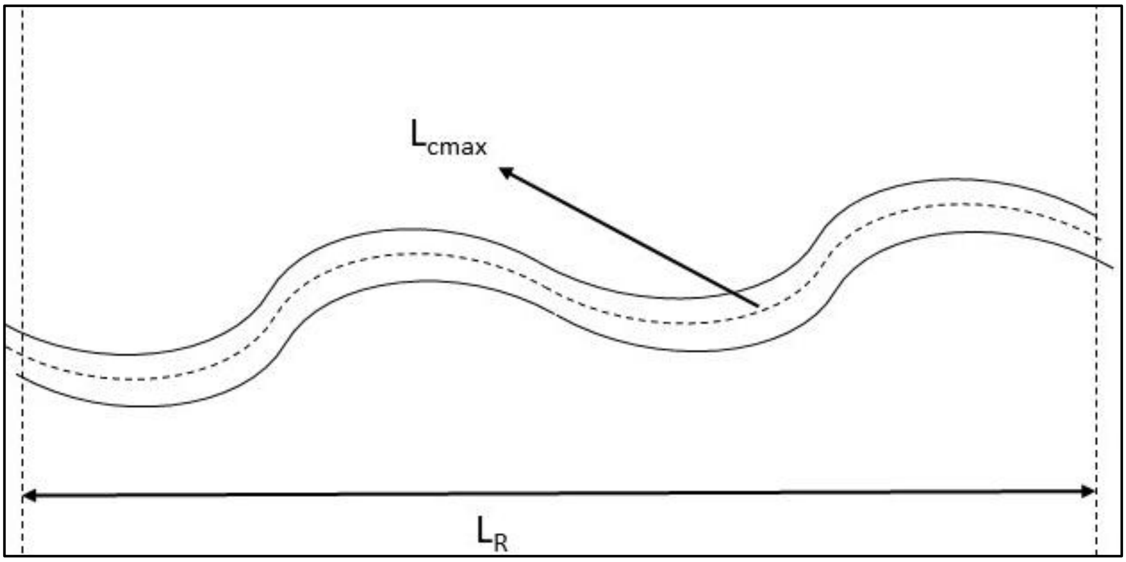

Figure 2.1 Diagram representing the calculation of the Sinuosity index for the single-channel

Sinuosity index of the reaches was measured in the present work using the method given by Friend and Sinha, (1993)[45]. In this method, the reaches were divided into equal-length reaches. The actual channel length and the straight path length are measured, after that the sinuosity index was calculated by the following equation for each reach:

$$P = \frac{L_{cmax}}{L_R} \tag{2.3}$$

Where P, is sinuosity index, L_{cmax} is the length of the midline of the channel (in single-channel) or the widest channel (in multi-channel) of the reach, and L_R is the overall length of the reach.

Ebisemiju (1994) investigated the Elemi river basin in Nigeria and suggested that the degree of sinuosity is controlled by the bank resistance which is influenced primarily by the nature of riparian vegetation and secondarily by the percentage silt/clay in channel bank sediment [46] Roy and Sinha (2007) studied the confluence dynamics of Ganga and Ramganga River using the geomorphological, and hydrological approach and concluded that an increase in sinuosity index influence the upstream migration of the confluence in the study area [47]. Thakur (2014) studies the riverbank erosion hazard in the Ganga river using remote sensing and GIS. He uses the sinuosity index with other geomorphic parameters (Braidedness Index and percentage of the island area) and found that there is a drastic increase in sinuosity index is observed. This increases in sinuosity index are observed due to certain factors like soil stratification of the river bank, presence of hard rocky area, and construction of Farakka Barrage as an obstruction to the natural river flow [48]. Khan et al., (2018) study the Yamuna river by employing a topographic map, digital elevation model (DEM), and satellite imageries. This study concluded that channel planform and sinuosity index are important indices which control the channel hydraulics, and stream power which determines the flow velocity and sediment supply to the downstream part of the channel [49].

2.4.2 River Network Change Index (RNCI)

The river changes its planform during the time, which can be successfully evaluated using RNCI [50]. The RNCI is a useful morphological index used to identify the current geomorphological process [51].The positive RNCI indicate that the dominant erosion process is taking place, and negative RNCI shows sedimentation in the river [52]. RNCI is calculated by given below formula.

$$RNCI = \left(\frac{\sum EA - \sum DA}{L}\right)/T \tag{2.4}$$

Where, Erosion area (EA), Sedimentation area (DA), Straight meander length (L), and the study period (T) are considered constant-1/event.

Yousefi et al., (2015) carried out for some changes of morphological parameters the Talar river using remote sensingand GIS during 1968 to 2013. RNCI was determined - 0.7 meters per year is observed in the river, which is mainly due to the sedimentation process [53]. Yousefi et al. (2017) study the effects of urbanization on river morphology using geospatial technology in Iran. The morphological and morphometric parameters were defined along an 11.5 km reach of river in which the RNCI was the main parameter to assess the sedimentation presses in the basin. The average of RNCI during the study period was about -4.1 m year-1, with the greatest channel change values of -6.12 m/ year recorded from 1966 to 1994 [54].

2.4.3 Radius of curvature

Leopold and Wolman, (1957) find that channel migration rate has a relation with channel geometry which is affected by the radius of curvature [55]. Heo et al., (2009) studied the Characterization and prediction of meander migration in the GIS environment for the Sabine River in the USA and concluded that channel migration is strongly correlated with bend curvature and that the maximum migration rate of the bend corresponded to a radius of curvature [bend radius (RC)/channel width (WC)] of 2.5 [56]. Hudson and Kessel (2000) examined the channel migration and meander-bend morphology for the lower Mississippi River between 1877 and 1924. This study concluded that the highest migration rates occurred with meander bends having a curvature, r_m/w_m (ratio between radius to channel width) between 1.0 and 2.0 [57].

The idealised plan- view of river meander is represented in the given figure (Fig. 2.2). The Radius of curvature (R_C) are measured from the remote sensing images of different years based on this model. R_C is the radius of a circle drawn around a meander bend .A single wavelength was assigned to the meander bendfor measuring of R_C. The measurement of R_C is done basedon circular arcs of known radius, which are superimposed on a meander bend, and the arc that best fit the channel centerline around the meander is selected to get R_C[58]. It expresses the degree of tightness of a single meander bend, with largeR_C values indicating wide-open meander bends. It is an important parameter which affects meander migration [24]. The tightness of a bend or bend curvature is determined through the ratio of the radius of curvature to the width of a channel. The channel migration rate is reliant on the tightness of the bend. It has been observed that a bend curvature ratio of 2.0 to 3.0 maximises the migration rate in temperate rivers, [59].

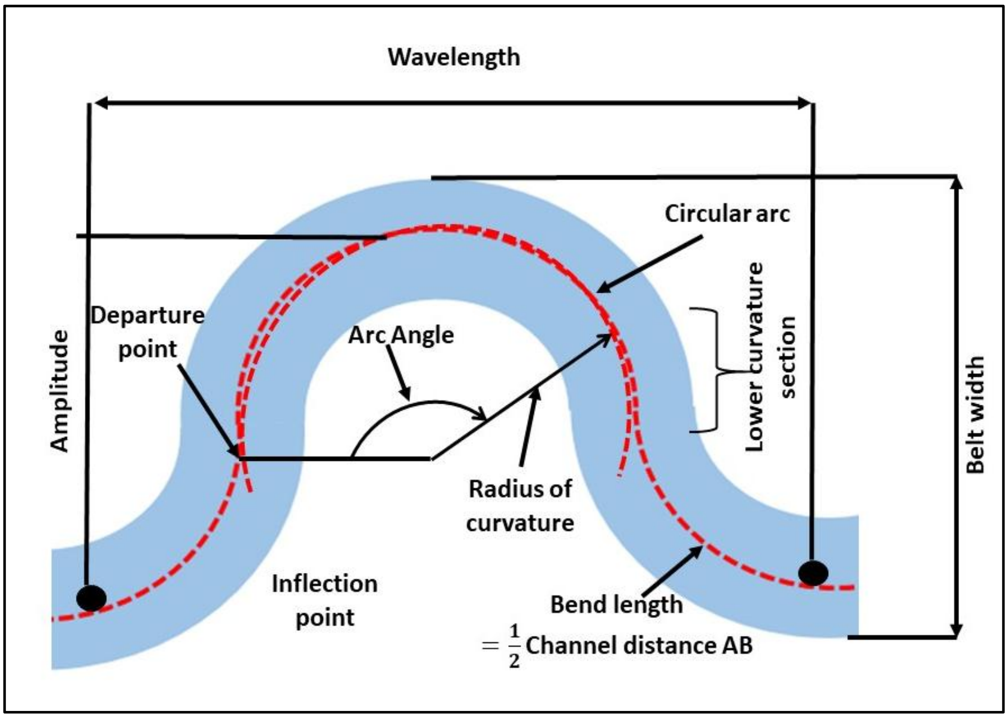

Figure 2.2 Plan-view sketch of idealized river meander (redrawn after Williams, 1986)

2.4.4 Centerline migration rate

Channel centerline migration rate is defined as channel activity along a river reach [60]. It has been measured in several ways by various scholars as dimensions of length per unit time.Yang et al., (2015) used the multi-temporal Satellite imageries to quantify the planform migration of the Yangtze River from 1983 to 2013 and to investigate the possible effect of human activities on the channel evolution. Results showed that the river was gradually changing to a straighter channel, with sinuosity reducing from 2.09 to 1.9 and river length decreasing from 125.32 km to 113.31 km in the past 30 years[61].Bufe et al., (2019) studies the controls on the lateral channel-migration rate of braided channel systems. On the basis of photographic and topographic data from laboratory experiments of braided channels concluded that migration rates are strongly sensitive to water discharges and more weakly sensitive to sediment discharges. In addition, external perturbations, such as changes in sediment and water discharges or base-level fall, can indirectly affect lateral channel-migration rates by modulating channel-bank heights [62]. It is calculated by dividing the sum of polygon areas for each bend by the length of the earlier of the two centrelines and the time between the two coverages. The methodology for measuring total channel migration between the two years is similar to that presented in the fig (2.3). [46, 47].

To calculate the channel-migration rate at each selected meander bend, the following equation was applied:

$$Channelmigrationrate = (ShadedArea) \div (LengthofT_1time) \div (T_2 - T_1) \tag{2.5}$$

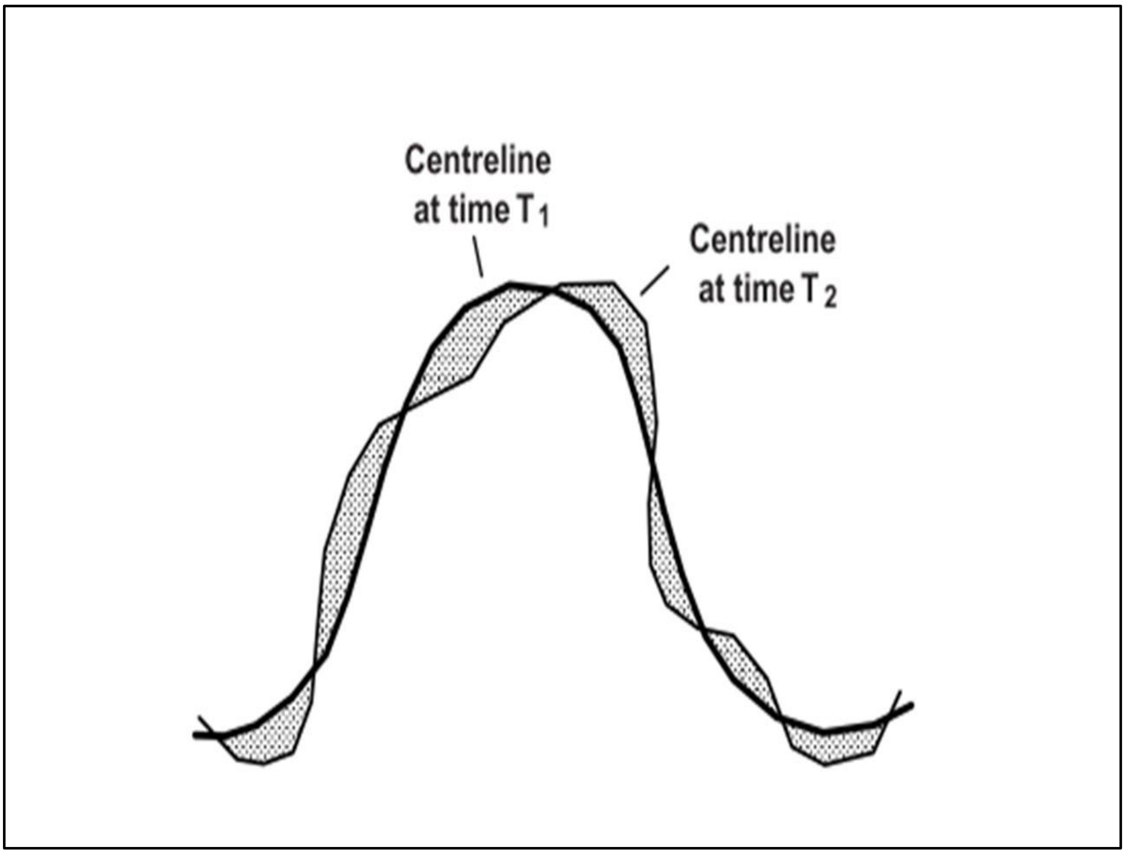

Figure 2.3 Determination of channel migration rate based on Shields JR et al.,(2000)

The published worksmentioned in the above section indicates a need for better understanding of meandering processes in large alluvial rivers. A physically-based model is required for estimating meander migration rates in suchhighly populated regions which can increase the basic knowledge of meandering processes in the alluvial channels. Such models are also crucial for the development of theoretical models, and to produce societal benefits to the society by helping, engineers, planners and other professionals in delineating flood plain hazard zones.

2.5 Extreme flood events

Flood is one of the main driving force to change the morphology of the river. Flood is one of the vital cause of erosion that occurs once every 50 years or more [64]. The flood also can be correlated with the mean annual erosion of a river [65]. The impact of such catastrophic events leads to the evolution of the landscape, which can also be related to the recovery time of the channel to its equilibrium form [65]. Evolution of landform by an extreme flood event cannot be the same in two different areas.It depends on the climate characteristics, location within the drainage basin, and the processes occurring in the floodplain. Although excessive erosion can happen in few channels during massive discharge in other rivers, even a 1000 year flood discharge may not take such significant erosion in the channel[50, 51]. Most of the sediment transported in river channels carried by the recurrent floods[64]. Such catastrophic flood events, which individually transport huge sediment loads, rarely occur in nature.

2.6 Frequency of floods

Floods provide a driving force which damages the riparian ecosystem, community or population structure, natural resources and the physical environment.

Riparian vegetation growth is controlled by the frequency, intensity and timing of floods [68]. The compaction of the deposited cohesive sediment is mainly dependent on the frequency of bank failure and bank erosion rates [69].

The vegetation growth tales place on bars and banks during the low discharge period. Therefore, thecritical parameter for vegetation growth is, the ratio between the time necessary for a given plant community to develop, T_v , and the recurrence interval, T_{fv} , of floods that can destroy the vegetation, e.g. mechanical destruction, burial and prolonged submersion in the flood water[54, 55].

These relationships can be understood by the equation (Eq. 2.6).

$$\tau_v = \frac{T_v}{T_{fv}} \tag{2.6}$$

Where the subscript v refers to riparian vegetation. The ratio$\tau_v$is useful to determine whether the vegetation growth is controlled by physical disturbance or not.

Riverbanks, cohesive soils consolidate with time and gradually become more resistant to erosion [72]. Therefore, another critical parameter for river erosion can be defined to characterize the stability of the cohesive river bank material deposited on floodplains and bar tops. In this case, it is the ratio between the time, T_c , necessary to the deposited material to reach a certain consolidation level (shear strength).It depends upon the type of materialsalso conditions and the recurrence interval of floods T_{fc} , characterized by intensity and duration, that are able to erode the channel. These parameters are expressed by the following equation (Eq.2.7). River erosion occurs when the shear stress exerted by the flow is higher than the shear strength attained by the bank material.

$$\tau_c = \frac{T_c}{T_{fc}} \tag{2.7}$$

In this equation subscript, c refers to consolidated material.

When both τ_v (Eq. 2.6) and τ_c (Eq. 2.7) are less than unity then the frequency of severe floods is too high.In this case,the river cannot have a stable channel which leads tothe development of meandering planform.

2.7 Fluvial erosion model

It is a standard method for computing long-term migration rate of planform usingthe migration rate and near-bank excess velocity multiplied by migration coefficient [57, 58]

$$\varepsilon^* = E_0\,(U_b^* - U_{ch}^*) \tag{2.8}$$

$\varepsilon^*$is the migration rate (with dimensions of the length over time), U_{ch}^* is the depth-averaged velocity at the channel centerline,U_b^* is the depth-averaged near-bank velocity and E_0 is the erosion rate coefficient (Eq. 2.8). The coefficient E_0 is typically determined through calibration of historical planform changes [75]. Therefore, the meaning of E_0 remains unclear becauseitdepends on physical characteristics of the channel or the bank material. Researchers generally agree that E_0 reflects the geotechnical properties of the river bank material and the effects of vegetation on near-bank flow characteristics with bank strength [60,61]. The coefficient may also vary with other channel characteristics such as bank height and local channel slope, local channel width and the availability of sediment for deposition on point bars [58, 60, 62, 63]. So this approach unable to effectively model the complexity of riverbank erosion at the meander scale, because it predicts a smooth centerline. To overcome the limitations of this model, Motta et al. (2012) has developed a Physically-Based (PB) model [7].

2.8 Physically-Based (PB) method for migration

The physically-based approach is more advanced and more accurate than the classic migration coefficient approach, mostly when modelling is done for more extended periods [7]. In this model relates the rate of migration directly to the physical processes controlling bank retreat, i.e. hydraulic erosion and mass failure.

The fluvial erosion rate, E^*, is defined by the following method (Eq. 2.9)

$$E^* = M^* \left(\frac{\tau^*}{\tau_c^*} - 1\right) = k^*(\tau^* - \tau_c^*) \tag{2.9}$$

Where, M^* is the erosion-rate coefficient, τ^* is the shear stress acting on the bank, and τ_c^* is the critical shear stress, k^* the erodibility parameter. k^* is found using the following relation with an erosion-rate coefficient (Eq. 2.10).

$$k^* = \frac{M^*}{\tau_c^*} \tag{2.10}$$

All the parameters e.g. M^*,τ_c^*, and $k^*$are all location-specific. The erodibility parameters are estimated in situ using a submerged jet erosion test which provides estimates of both τ_c^*andk^*. Alternative instruments such as the cohesive strength meter (CSM) provides only the critical shear stress (τ_c^*)[80] .The advantage is therefore taken of the strong inverse relationship between τ_c^* andk^*[81] with k^* being calculated using an empirical relationship (n = 83; r^2 = 0.64) derived from jet testing data obtained by Hanson et al. (2001) (Eq. 2.11)[81].

$$k^{*} = 2 \times 10^{-7} (\tau_c^{*})^{0.5} \tag{2.11}$$

Which can be rewritten in terms of erosion-rate coefficient in m/s as shown in the following relation (Eq. 2.12).

$$M^{*} = 2 \times 10^{-7} (\tau_c^{*})^{0.5} \tag{2.12}$$

However, the field data from the jet test are not available; an approximate estimation of critical shear stress is calculated using the third-order polynomial fitted to the results of Julian and Torres (2006). (Eq. 2.13)[67, 68].

The critical shear stress is calculated using the silt-clay content percentage form the soil sample collected from the riverbank of the Ramganga.

$$\tau_c^{*} = 0.1 + 0.1779(SC\%) + 0.0028\,(SC\%)^2 - 2.34 \times 10^{-5}(\mathrm{SC}\%)^3 \tag{2.13}$$

Where, SC = silt-clay content in percentage.

2.9 Meander migration

Meander migration is a process by which a river changes its planform spatially in the floodplain. Active meandering rivers adjust their channel planform depending on spatial and temporal variation in channel morphology, sediment load, discharge, and properties of bank material. The water coming from the upstream channel is directed towards the outer bend of a meander by centrifugal force which leads to superelevation of water level in the channel. This possesses leads to erosion in the outer bank of the river, and the eroded sediments are transported to the inner bend. This prosses suggests that the maximum erosion has occurred just at the downstream of the apex, which results in down valley translation of the meander bend. Four models have been identified for the meander migration, e.g. translation, rotation, extension and a combination of the three [85]. Extension of meander refers to the growth of the meanders, whereas translation indicates the migration of the meander bends.

Numerous models have been developed for river migration based on the fundamental models of physics and probability. These models showed thatthe evolution of a variety of meandersin the floodplain[70–72]. Geology and neotectonics play an essential role in channel migration due to their influence on channel slope, sediment production and storage [20, 56].

2.10 Models of meander migration

The reason behind the meander migration has attracted many researchers fora long time, but a satisfactory explanation of this process has not been achieved[89]. Many theory has been developed to explain this phenomenon including minimization of energy expenditure [90], dissipation of excess energy [91], and minimization of the variance in bed shear stress and boundary friction [92].

Meandering starts when a specific threshold discharge is reached in a straight channel, and the channel thalweg begins to migrate back and forth across the channel. As discharge increases, oscillations of the thalweg increase in floodplain until one of the river banks are impacted by the core velocity and then erosion starts[93]. Secondary circulation is an essential factor of flow in a meandering channel. Centrifugal force acting on the water as it moves around the evolving meander causes a slight elevation in the water surface along the concave bank of the meander. This difference in water elevation produces a variation in pressure across the section that gives the flow in a circulating motion, called helicoidal flow [94]. The midsection of the channel contains the majority of the discharge that moves downstream in a corkscrew motion, but near the outer bank, at the boundary layer between the water and the bank sediments, differences in pressure cause the water to move upward along the bank and then outward toward the centre [95]. The flow direction of this cell is opposite to that observed in the middle areas of the channel. The two rotating flows meet at the surface in a zone of convergence that promotes erosion at the outside bend. At the inside bank of the bend, there is a net outward component of flow that favours deposition of sediments at this area, creating a point bar [94]. With the passage of time, the meander bend evolves in the channel.

Many theoretical and empirical approaches have been used for the development of predictive models for meander bend migration. These theoretical and mathematical models are based on simplified physical principles. Such types of models can be categorised in two ways: first types of model is based on equations that describe dominant physical processessuch as Ikeda and Parker (1981)[74], and the second type of models that hypothesize a condition regarding the behaviour of stable river channels, such as minimum stream power [90]. The physically-based model is established on the Ikeda and Parker (1981) model, which estimates the bank's velocities and erosion rates for a channel reach using one or more bends of a specified dimension, flow conditions in the river and planform geometry of the river[74].

2.11 Types of models

Different types of computational models have been developed over the last decade, which simulates characteristics of the alluvial system. These models can be classified as (i) mathematical techniques (statistical, analytical, and numerical) (ii) through modelling techniques (black-box, process-based, and optimization), (iii) by computational methods (finite difference, and finite element, cellular automaton), but the most fundamental classification concerns what the models simulate, or attempt to simulate [96].

Another classification of the model can be done on the bases of impacts of environmental changes on the fluvial system.These models are (i) Flow models- which simulate fluxes of water through a channel and (ii) Geomorphic model which simulates the fluvial landform and topography of channel. The flow models have been shown in the fig. (2.4) which include the (A) hydrological model and (B) flood inundation model. The geomorphic models can also be classified into (C) channel morphology models, (D) alluvial stratigraphic models, (E) meander models (F) braided river models, (G) channel network models and (H) landscape evolution model [97].

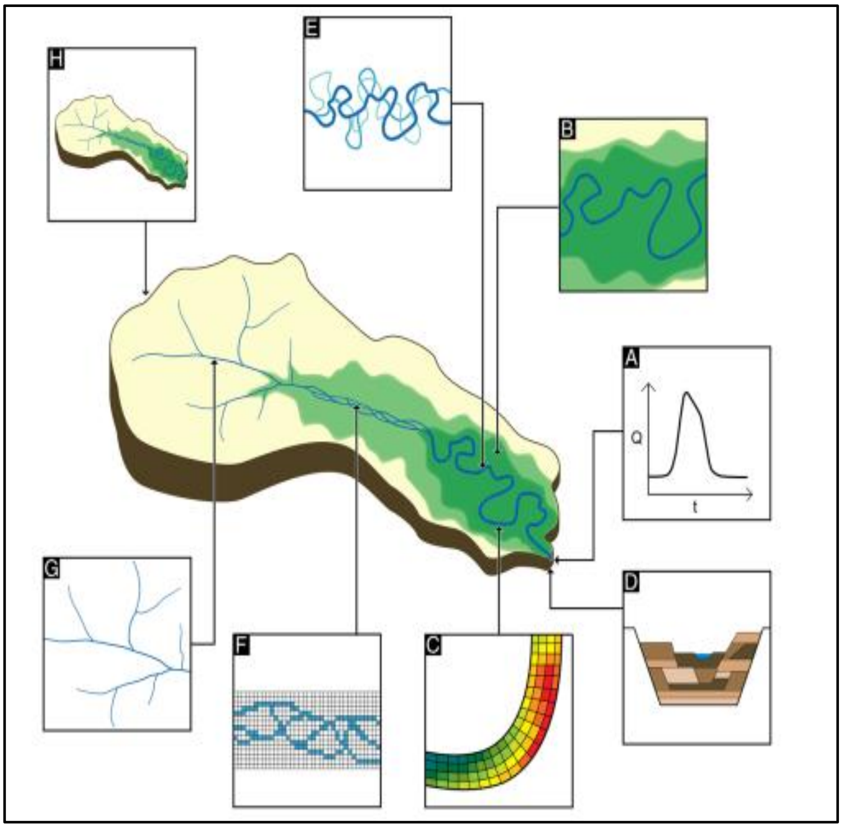

Figure 2.4 Schematic view of different model types for simulating river systems. A: hydrological; B: floodplain inundation; C: channel evolution; D: alluvial stratigraphy; E: meandering, (based on Van De Wiel et al., 2011)

Meander evolution models are the best model for prediction channel behaviour of the meandering river. Such models simulate the evolution of channel planform dynamics in the single-channel meandering river for several years (Fig. 2.4 E). These meander models simulate channel flow data to drive a simple hydraulic bank erosion mechanism from which channel migration rates are estimated [82,83]. RVR meander model is physically based model in which the flow and soil properties data are used to predict the future planform of the channels.

2.12 RVR meander model

The current version of RVR meander migration model includes the hydrodynamic model with the bank erosion model CONCEPTS (Conservational Channel Evolution Pollutant Transport System) [6, 84].This model can reproduce a wider variety of planform shapes such as high skewness and sharp necks compared to the classic approach of migration coefficient [6, 58]. In addition, this model can produce more realistic different shapes of meander loops in rivers like skewed meander bends, compound loops, and rectangular shapes [101].

The modelling of channel planform dynamics in RVR meander model requires the simulation of these parameters: (i) hydrodynamics, (ii) sediment transport, (iii) bed morphodynamics, and (iv) bank erosion. This model was developed for modelling channel restoration and naturalization processes in meandering rivers. The present version of RVR meander has two modules. The first module calculates the morphological parameters of natural rives based on a statistical analysis of sinuosity, rate of migration, fattening and skewness [102]. This module is essential when analysing a stream quantitatively and qualitatively for future planning purpose. The second module presents the planform migration model itself, where a riverbank erosion sub-model is applied using the concept of near-bank velocity [74].

The RVR Meander model works in two modes as (1) a standalone version from the command line in MS Windows or Linux, and (2) through an ESRI's ArcMap plugin version 9.3.x or 10.x software (Fig. 2.5). The working process is the same for both modes. The software, its manuals, and tutorial files can be downloaded at the URL http://rvrmeander.org.

The stand-alone version requires four input files: (1) "valley.txt," pairs of the easting and northing coordinates of the valley centerline; (2) "testdata.txt," pairs of the easting and northing coordinates of the initial channel centerline; (3) "prototype.cfg," general parameters for simulation; and (4) "InitialSectionProperties.dat," initial configuration of channel banks (shape and bank material properties) for the physically-based approach for meander migration.

The physically-based approach in RVR meander model required four input files (i) "InitialSectionProperties.dat," initial configuration of channel banks (shape and bank material properties) (ii) "prototype.cfg," general parameters for simulation; (iii) "valley.txt," pairs of the easting and northing coordinates of the valley centerline and (iv) "testdata.txt," pairs of the easting and northing coordinates of the initial channel centerline. These files are prepared in ARC GIS environment and a separate Excel file "Initial Section Properties Generator.xls" is available for automatically generating the file "InitialSectionProperties.dat" which provide the cross-sectional data for modelling. The output files for the standalone version are designed to be post-processed using such software as Tecplot and MS Excel. The ArcMap plugin generated files can be directly viewed inside ArcMap with the exception that the current version does not support "Bank geometry output," and needs plotting software such as MS Excel to view model output [103].

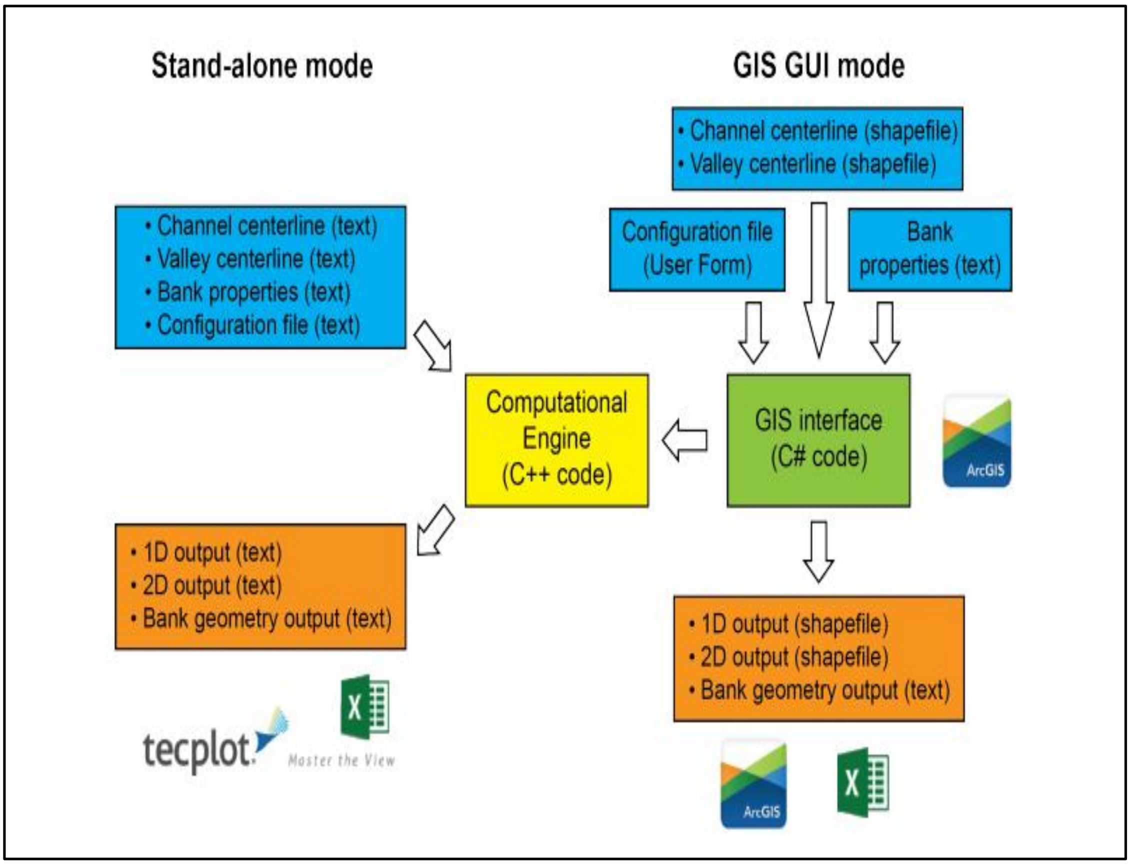

Figure 2.5 RVR Meander software is available as a stand-alone program for MS Windows and Linux operating systems and as a plugin for ESRI's ArcMap (based on Eddy J. Langendoen et al., 2015.)

2.13 Summary

The literature review on the modelling of channel planform dynamics suggests that such meandering rivers deserve serious attention towards the understanding of predictable behaviour of such alluvial rivers. Thus the Ramganga river has been modelled in GIS environment on the bases ofan above-discussed aspect of fluvial geomorphology to characterise its behavioural pattern in the downstream area, and it provides insight into fluvial morphological processes which are responsible for its planform dynamics. An attempt has been made to utilise remote sensing and hydrological data to model the planform dynamics for the next 100 years in the GIS environment.