Assessment of River Evolution and Channel Migration Rates in the Fluvial Regime of Punjab Province of Pakistan

Burira Anam, Junaid Aziz Khan, Bilal Ahmad Munir

***Abstract*— River channels tend to modify and migrate due to both anthropogenic influences and continuous natural changes in environment, so can be subsequently lead to catastrophic effects in case of floods. With the improvements in geospatial analysis and availability of massive dataset it is possible to study fluvial regimes in detail. Aim of this research was to identify potential migration river channel zones and to assess the degree of evolution in past two decades. Features analyzed, to assess evolution, were River width, braid-channel ratio, river sinuosity and riparian vegetation. River migration zones were identified based on data from 1990 to 2010 and it was found that substantial potential river migration zones are at Indus river in Rajanpur district, Chenab river in Muzzafargarh and Jhang districts ,moderate potential migrating zones are at Indus river (in some zones of Rajanpur, DG Khan and Mianwali), Chenab river (in some parts of Jhang and Muzaffargarh), Jhelum river (in Jehlum and Khoshab), Ravi river (at end of Lahore), and Sutlej river (near Pakpattan and Vehari districts) while all other zones were observed to be falling in least potential migration zones. In most potential migration zones, further calculated attributes, that were river width, braids-channel ratio, river sinuosity and riparian vegetation, were found to be undergone through change at much impressive rates than other zones. Understating river's response in channel migration is essential to set reliable targets for restoration efforts.**

***Index Terms*—River Evolution, Landsat, Sinuosity, Channel Migration**

I. Introduction

The term 'river evolution' refers to the development and growth of river system over a specific period of time. Rivers grow in terms of network pattern, drainage area, channel and profile geometry. These variations can be seen at both the spatial and temporal scale. Rivers tend to change its shape directly or indirectly affecting the whole basin's geomorphological characteristics.

The aim of this study was to monitor and assess the potential stream evolution to understand the level of environmental degradation of the Indus basin and its tributaries in Punjab province-Pakistan. River channels tend to modify and migrate due to both the anthropogenic influences and continuous natural changes in the environment. Anthropogenic changes affect fluvial environment by affecting the channel stability [35]. Naturally, rivers are dynamic entities, continuously reacting to changes in local environment and variations in sediment load and run-off from upstream on large scale [22], [19]. When previously undeveloped watershed areas are transformed into urbanized areas, the river try to accommodate flashier and higher discharges and transform to a new hydrologic regime [19]. This attempt of transformation makes banks and beds more unstable leading to transportation of large amount of sediment into the river system. Resultantly, river shows more dynamic behavior, higher channel migration rates and increased transport of sediments due to watershed disturbance [25]. Thus, the key issue is to have the capacity to efficiently monitor river evolution in a way that permits to recognize the amount of disturbance induced by humans and environmental change [25].

A. Meandering and Selected Features of River Evolution

To maintain equilibrium state rivers naturally adjust their way forming different channel patterns. Based on flow patterns, rivers are categorized into three major classes: straight, meandering, and braided. However, this classification is arbitrary [31].

Meandering type of rivers are characterized by sequence of oscillating meander loops. Meander loop is the small portion of river reach that lies between two inflection points.

An actively meandering stream is powerful enough to deform its channel boundaries through active bed scour, bank erosion, and point bar growth. Active meanders are the result of contemporary fluvial processes. They evolve and respond to every discharge event with sufficient stream power to mobilize bed and bank sediments. Conversely, stable meandering channels lack energy or erosive ability. They do not migrate appreciably within a small time span and generally pose little or no risk to surroundings [31]. These channels adjust their shape and gradient to make transport of sediments and water possible. After this effort no more degradation, aggradation, narrowing or widening of channel happens. Therefore, only the sediment and discharge are independent variables of these kind of channels [14], [21], [23] confirm that channels possessing wide and shallow cross section are best able to transport large amounts of bed load [31].

Integrated flood management is not possible without studying river behavior and its morphology. It involves understanding rivers in context of lateral migration, bank erosion, changes in river course, lateral migration to a large distance, over bank spilling due to insufficient channel capacity, frequent formation of new channels, and river beds rising, all considered as possible causative factors resulting in floods. This highlights the dire need of paradigm shift from localized and traditional approach to integrated one. Effective use of river resources and implementation of strategies can help to preserve the productivity of floodplains and reduce losses due to floods [5], [27].

A number of countries (major portion fed by India, Pakistan and Afghanistan) share the Indus River Basin. But chief portion of the Indus main stem and its four main tributaries (Chenab, Jhelum, Ravi and Sutlej) passes through the lands of Pakistan. Both Pakistan and India, since 1947, have suffered many minor and major riverine floods with a significant loss of life [39], [38], [37]. Some major floods in history like back in 1992 cost the country about 3% of its total GDP. However, the flood of 2010 plays havoc with total losses of 9,500 million US $.

The morphology and behavior of a river reach are strongly determined by the water and sediment discharges from upstream. In dynamically adjusted systems the rate of lateral migration increases with the supply of water and sediment from upstream. Changes in run-off and sediment yield, as a result of natural processes or human activities will trigger changes in rates and modes of channel migration. Locally, distribution of water velocity and properties of bank and bed materials will control the channel behavior. Therefore, local channel morphology such as dimensions (e.g. width), pattern (e.g. sinuosity), shape (width/depth ratio) and gradient will not only reflect upstream controls but also provide information on the direction and rate of channel migration. As a part of quantitative evaluation of the stream attributes (Riparian vegetation, Sinuosity, Braid-channel ratio, Channel width and Rate of migration) were quantified and analyzed.

B. Migration Rates

It is also beneficial to calculate rates of change in a river channel in discrete temporal framework (Albuquerque, Espinoza et al., 2013). The rate of lateral migration is dependent on bed and bank material, riparian vegetation, topography, flow properties and tectonic activity [16], [28], [17], [26].

The Digital Shoreline Analysis System (DSAS) is basically an extension of ArcGIS® that calculates rate-of-change measurements and statistics using more than one temporal shoreline in GIS environment. It is basically designed to quantify rates of changes and shifts in shorelines [6].

But in this research it was used for river channels migration. DSAS provides with three types of rates of change EPR (End Point Rate), NSM (Net Shoreline Movement) and SCE (Shoreline Change Envelope)

$$EPR = \frac{\text{Distance between oldest and latest river center line}}{\text{Number of years}} \quad (1)$$

$$NSM = \text{Distance between oldest and latest river center line at each transect} \quad (2)$$

$$SCE = \text{Distance between farthest and closest to the baseline line at each transect.} \quad (3)$$

II. Study Area

The regions lying along rivers remain vulnerable due to the lack of local government interest towards watershed(s) and river management. To examine the hydrological and geomorphological degradation of rivers, Punjab province of Pakistan was selected as study area as shown in Fig. 1.

A. Salient Features

Surface water resources of Pakistan primarily depend on the flow of the River Indus and its tributaries. The drainage area of River Indus is approximately 966,000 sq. km with a stream length of 2,900 km [18], [2], [27].

The rivers of Indus basin are heavily dependent on the seasonal recharge that comes from two main sources a) Rainfall b) Snowmelt in summer season. Also the rise in river waters in monsoon season varies due to the amount of water discharged by the neighboring country-India. Punjab rivers have diverse flow properties and all of them generally start to rise in the springs and in beginning of summers because of both the monsoon rains and snow melt on the highlands causing a collective peak discharge in July and August. The river shows least flow in winter season (November to February) where, average monthly flows are merely about one tenth of those in summer season. Besides, there are several small streams which are seasonal and rain reliant and are dry during winters, while rainfall is neither enough nor consistent [27].

The amount of precipitation and the volume of deluge are far more than can be consumed readily. A big part that is about 70% of the precipitation either floods in the riverine zones and origins consecutive glooms and harms or flows into the sea without any profitable benefit to the country. The southern Punjab observes very little yearly rainfall averaging less than 152 mm. On the contrary, areas overhead the Salt range containing the districts of Jhelum, Rawalpindi, Attock, and Mianwali receive much higher rainfalls averaging above 63.5 mm per year [18], [27].

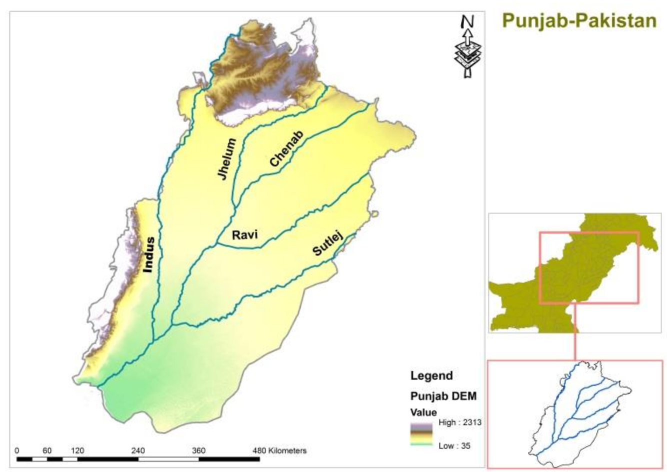

Fig.1. Study Area

III. Methodology

The current study aims to understand the level of environmental degradation of the Indus basin and its rivers in Punjab by monitoring the inconstant behavior of the river(s). Remote sensing and image processing technique, with an equitable grade of accuracy encompassing period of past 20 years from 1990 to 2010, was used. Indices approach was used to evaluate stream attributes using RSI's ENVI ™, Leica Geosystem's Erdas Imagine ™, ESRI'S ArcMAP™, MapInfo™, and Global Mapper™, The U.S. Geological Survey's DSAS™, and Hawth's tools ™. Landsat imagery was used to achieve the objective. River behavior as a whole was analyzed in three phases: data acquisition and preprocessing, quantitative evaluation of the stream attributes and analysis.

A. Data Requirements and Availability

Examining river activities and change over a long period of time requires satellite data with specified time gaps. Deviations in platform characteristics and morphology of rivers of Punjab were analyzed using multispectral images of Landsat-5 TM and Landsat-7 ETM+, encompassing the period of thirty years (1990-2010). Images of whole Punjab province were acquired for 1990, 2000 and 2010. Landsat covers Punjab province in 13 tiles and LandSat-5 TM and LandSat-7 ETM+ WRS-2 descending were acquired for each year, as shown in Fig. 2. (b). Landsat images have been used extensively to study river behavior and river mechanics [36], [12], [34], [20], [9], [13], [33], [13],[3].

Methodology followed was sub divided into two phases

1. Data acquisition and Aassimilation.
3. Quantitative evaluation of the stream attributes;

B. Data Acquisition and Assimilation

LandSat-5 TM and LandSat-7 ETM+ data for Punjab province was used for years 1990, 2000 and 2010 and were pre-processed.

Satellite images for years 1990, 2000 and 2010 were acquired and were stacked. "Layer Stacking" was used to produce a multi-band layer from a number of georeferenced images. In this procedure the input bands are re-projected and resampled to a mutual user-selected pixel size and projection. The data acquired was already rectified and projected in Universal Transverse Mercator (UTM) system.

As study area was covered by 13 tiles (Figure 2) for each year and to cover definite area it was required to combine numerous satellite imageries into a single satellite photo for

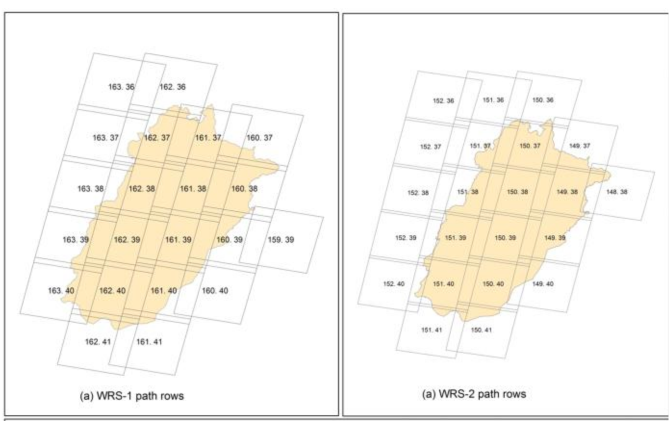

Fig. 1. WRS-1path row (b) WRS-2 path row

advance processing so all 13 tiles for each year were mosaicked as single image.

In spatial sub setting, mosaicked image was clipped according to Punjab administrative boundary and analysis was performed specifically on the subset area.

Transforming spectral radiances in to the spectral reflectance is called atmospheric correction, removal or compensation [1]. Images were atmospherically corrected using QUAC (Quick Atmospheric Correction) model to get more accurate results.

Density slicing has recognized to be principally beneficial technique for classifying various land cover categories within satellite images [24], [30]. Density slicing includes separating the brightness values of a particular band into distinct breaks. In band 7 water class threshold range was set for all three years and then extracted as a unique class, later these were converted into shapefile format for further processing. Using thinning tool available in Arc Map ™ these river features were thinned to get the center lines of rivers.

C. Quantitative Evaluation of Stream Attributes

(a) From the data prepared in phase 1 quantitative information, that was directly or indirectly addressing the stream, was extracted at multiple but equidistant points of rivers. Braid-channel ratio, stream width, vegetation density, and sinuosity were quantitatively measured for all three years that are 1990, 2000 and 2010.

(b) Rate and degree of migration and evaluation of streams at the distance of 3 km on rivers within these years were computed using DSAS. Later, using these results encompassing 20 years, potential migration zones of rivers were identified.

1) NDVI and Vegetation Delineation

Normalized Difference Vegetation Index (NDVI) is the image digital processing technique that includes reflectance connections in the visible and NIR. NDVI method focuses image algebra and is defined as (4):

$$\frac{((NIR-Red))}{((NIR+Red))} \tag{4}$$

As discussed earlier, it is a major factor in river evolution and lateral migration, vegetation density using NDVI was extracted, on right and left banks of rivers at the distance of 5 km for all three observed years.

Indus River flows with continuous procedures of erosion and deposition mechanisms. Formed alluvial plains are occupied by pioneer species of plants and with the passage of time grows to form a usual climax riverine forest. Sooner or later river erodes and engulf these planted zones. While on the other side sediments are deposited to form huge side bars that form new fluvial plains. Regular formation of fluvial plains by the process of continuous erosion and deposition is a salient feature of Indus. The Indus region is yearly inundated during monsoon season (July and August). Natural pathways of Punjab Rivers and their flow are intruded by extensive irrigation works like diversions, reservoirs and canals [15], [4], [32].

2) Geomorphic Attributes

Among all geomorphic attributes of a river that change with the passage of time, in result of environmental and human-interaction with environment, sinuosity, braid-channel ratio, stream width and lateral migration rates are quantified.

Sinuosity is the degree at which river deviates from its straight path. In real world scenario, it is not possible for a river to flow in the straight-line path because there are many factors (for instance increased flow velocity, volume and erosion) that force the river to deviate from its straight path. This deviation and different flow patterns are because of sediment load, variability of water discharge, bedrock outcrops, tectonic influence and anthropogenic activities. Tectonic movements are also the cause of change in river gradient [5],[29]. Sinuosity of all river reaches for all three years (1990, 2000 and 2010), was calculated using Hawth's tools in ArcGIS environment and results were tabulated for further analysis. Hawth's method quantifies sinuosity using (5):

$$Sinuosity = Actual\ path\ length / Shortest\ path\ length \quad (5)$$

Second attribute is braiding or braid-channel ratio that is the quantity of river channel multiplicity. It shows the tendency of a channel to grow into multiple channels over time and controlling factors are bed load and suspended load residue [8], [11], [7], [33]. Braid-channel ratio was calculated for all rivers for years 1990, 2000 and 2010 so that river morphology and stability of streams can be observed clearly [4], [32], [15].

Next calculated attribute is channel width for years 1990, 2000 and 2010 was observed and averaged for whole river reach for further study and to discuss the stability of the rivers. Stream width generally depends upon the volume and velocity of water flow, the density and type of riparian vegetation along the beds, and also on the amount and kind of sediments transported. In simple words, water channels with greater flow normally ensure deeper and wider channels [10].

Last attribute is Rete of lateral migration within 20 years. River centerlines extracted in phase 1 for all three years (1990, 2000 and 2010) were used to get the rate of change in the river paths to get potential migrating channel zones using DSAS (Digital Shoreline Analysis System) at equidistant transects (3 km apart). Rate of migration at equidistant transects were computed, tabulated and mapped. Using these results encompassing 20 years, potential migration zones of rivers were identified.

IV. RESULTS AND DISCUSSIONS

A. Potential Migration Zones

Classified river migration zones were identified and mapped. It was found that substantial potential river migration zones are at Indus and Chenab River, as shown in Fig. 3. Red points represent the zones with the maximum change over past two decades, in terms of migration, over last two decades. Blue points are moderate potential migration zones and peach colored points are having least potential to migrate.

All rivers show a hasty behavior towards the stream migration phenomena. The possible reason includes the frequent occurrences of floods in Pakistan from past decade. Indus River was sub-divided in to five zones:

- Chakwal Sub-watershed (Zone 1)
- Mianwali Sub-watershed (Zone 2)
- Layyah Sub-watershed (Zone 3)
- Muzzafargarh Sub-watershed (Zone 4)
- RY Khan Sub-watershed (Zone 5)
- Rajanpur Sub-watershed (Zone 6)

In Indus River, substantial migration zones are near Rajanpur district and Bhakkar district (zone-06) as shown in Fig.3.

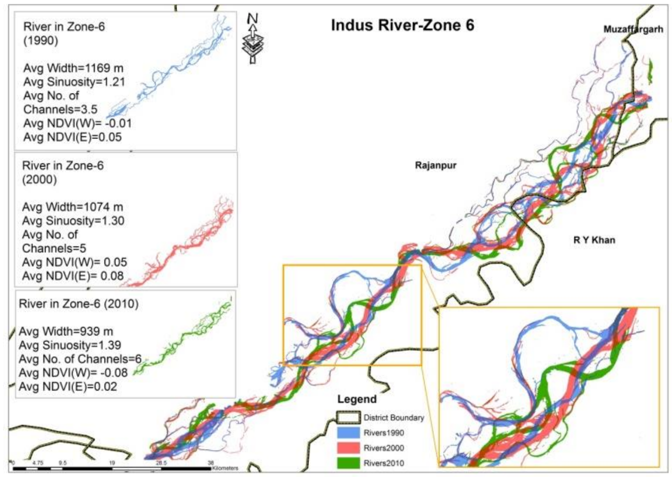

Fig. 3. Indus River zone 6 migration scheme.

By similarity Chenab, Sutlej, Ravi, and Jhelum rivers are divided in to 6, 3, 3, and 3 sub-zones respectively. Chenab River shows maximum migration near Muzzafargarh and Jhang districts (zone 3), Fig 5. Maximum potential was observed in Indus and Chenab Rivers, however moderate potential in stream migration is observed in Indus, Chenab, Jhelum, Ravi, and Sutlej Rivers.

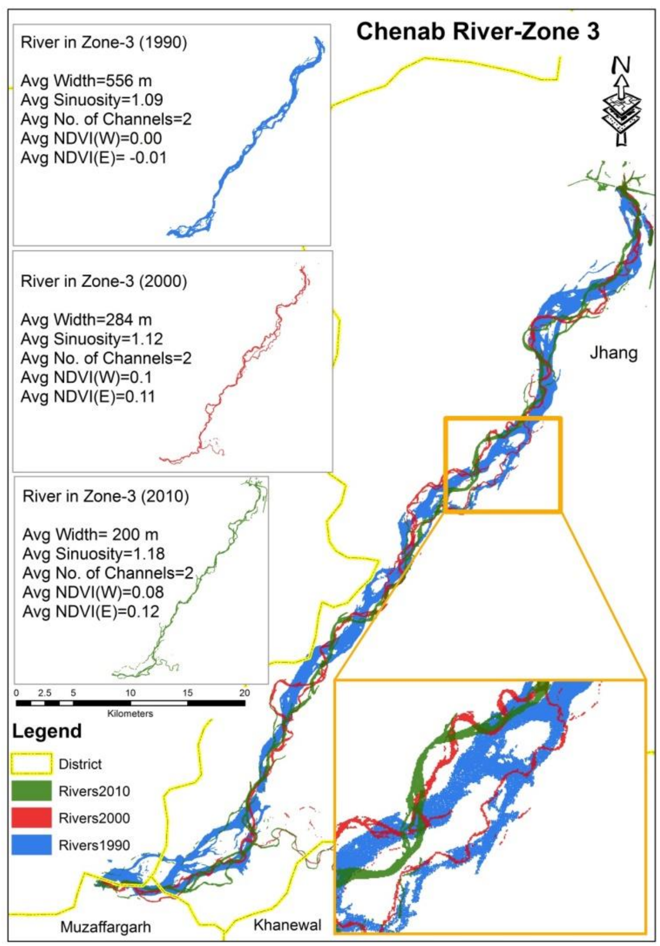

Fig. 4. Chenab River zone 3 migration scheme.

Zone 6 (Rajanpur, DG Khan) and 2 (Mianwali) shows moderate potential migration zones at Indus river. Whereas, zone 3 (Jhang and Muzaffargarh), zone 1, 2 (Jhelum, Jhang), zone 1 (Lahore), zone 1 (Pakpattan and Lodhran) show moderate potential migration of streams in Chenab, Jhelum, Ravi, and Sutlej Rivers. However, all the other defined zones are observed with least potential in the migration of streams as shown in Fig. 5.

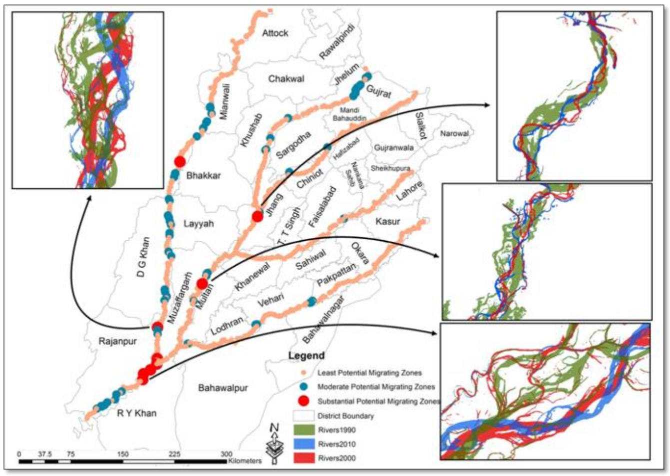

Fig. 6. Classified potential migration zones in Punjab province

B. *Evaluation of Stream Attributes*

Average width, sinuosity, braid-channel ratio and vegetation on eastern and western banks of all rivers were calculated. As discussed earlier, Punjab is anthropogenically modified plain with climate change, so change in all these calculated factors are justified with the modification in climate and plain. Sinuosity, mainly, increases with the increase in silt-clay content of channel boundary i.e. lithology and flow velocity. Braid-channel ratio is mostly characterized by discharge and resulting capacity of transport bed-load. Width of a channel is affected by cumulative effect of flow volume, velocity and bed-load sediments. Keeping all controlling factors (that are human induced changes, flow volume and velocity, bed-load, lithology) constant, inter-dependency of attributes is like more flow should result in increased width with decreased sinuosity and braid-channel ratio. As, naturally, it is impossible to keep all these factors constant so, results show little fluctuation from previously defined standard. Along with all attributes, riparian vegetation was also observed and it was noticed that there is almost no or negligibly small vegetation along banks in whole Punjab province as shown in Table 1. By this finding it can be concluded that river evolution in Punjab is least affected by riparian vegetation.

Overall, width of Indus River is decreasing at subsequent scale and opposite to width; sinuosity and braid-channel ratio are increasing with time. Chenab shows the same behavior, width of river Chenab is decreasing at significant level and opposite to width; sinuosity and braid-channel ratio are increasing with time. Jhelum shows a fluctuating behavior over last 20 years. In first decade width was observed to be decreasing while sinuosity and braid-channel ratio were increasing. Opposite scenario is observed in last decade where width was comparatively but slightly increased while braid-channel ratio and sinuosity were slightly decreasing. Ravi River shows a frequent decline in width but its braid-channel ratio and sinuosity is almost constant. Sutlej River shows constantly decreasing width trend with slight increase in sinuosity and constant braid-channel ratio (Table1).

	Year	Width (m)	Sinuosity	Braid-channel ratio	Veg (West)	Veg (East)
Indus River	1990	1585.19	1.17	4.35	-0.01	0.06
	2000	1533.61	1.28	5.71	0.03	0.07
	2010	923.81	1.30	7.01	-0.09	-0.04
Chenab River	1990	1685.17	1.09	2.09	0.05	0.02
	2000	389.23	1.21	2.42	0.17	0.12
	2010	370.88	1.30	3.55	0.11	0.06
Jhelum River	1990	806.36	1.15	2.21	0.07	0.02
	2000	198.96	1.25	3.20	0.12	0.17
	2010	320.57	1.10	2.80	0.09	0.16
Ravi River	1990	234.97	1.10	1.11	0.01	0.00
	2000	144.78	1.12	1.32	0.17	0.14
	2010	88.87	1.13	1.00	0.15	0.12
Sutlej River	1990	673.70	1.22	1.10	0.28	0.25
	2000	176.08	1.30	1.16	0.29	0.24
	2010	124.68	1.35	1.15	0.13	0.16

Table 1. Change in river's attributes over past two decades (1990-2010).

V. CONCLUSIONS

As a case study, this research was carried out for identifying potential migration zones in case of riverine floods in Punjab province and to evaluate stream attributes to examine the river evolution and stability, based on past data of two decades from 1990 to 2010. Stream attributes addressed river width, sinuosity, braid-channel ratio and riparian vegetation.

This study shows that zones with maximum potential to migrate are at Indus river and Chenab river while, apart from least potential migration zones, moderate potential migration zones were distributed on all rivers. Calculated stream attributes reveal that some river reaches of Indus and Chenab show unstable behavior in last two decades and have tendency to be vulnerable in case of floods with a major trigger or change in controlling factors. It is observed that riparian vegetation is negligibly small in whole Punjab province and that's why least contributing towards the river stability.

As there is no study conducted following integrated approach for flood management and river stability in Punjab, Pakistan using GIS techniques so far, this study will be useful for organizations working on improved flood and river management. This study is also significant because facts on development in river course are valuable to the experts and planners who are concerned with the management of river basins, and of water resources of the country. More significant understating river's response in channel migration and this understanding is essential to set reliable targets for restoration efforts.

A. Limitations:

• Trade-off was practiced for some of the river stability controlling factors.

• More detailed data of soil composition, surveys and past reports on river behavior could have helped in getting more sophisticated results. Consequently, the results with these restrictions may not be 100% accurate but gives a fair idea of the relative potential of migration and stability of rivers in Punjab province of Pakistan. These results can be set as a base for further revised research(s) and management efforts.

• It is suggested that indices results should be verified with on-ground verification to attain more accuracy but selected study area was too large to be surveyed.

VI. RECOMMENDATIONS

In evaluating stream attributes, not all characteristics were considered. The proposed methodology is flexible and can be modified by incorporating several other characteristics of rivers for more detailed results. Moreover, with its flexibility the methodology can be implemented as a whole for river management projects in Sind province with some minor edits. Furthermore, for stability analysis, further studies should incorporate geological factors and on-ground survey results with this methodology for more accurate and more practical results. Finally, Decision makers and investors can preferably use this scheme for improved flood management, river management and restoration projects.

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