ASSESSMENT OF THE IMPACT OF SAND MINING ON THE MORPHOLOGY OF THE SEVERELY AFFECTED REACH OF BHARATHAPUZHA RIVER BETWEEN PATTAMBI AND KUTTIPPURAM USING REMOTE SENSING AND GIS

By

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(2015-18-009)

THESIS

Submitted in partial fulfilment of the requirements for the degree

Master of Technology

In

Agricultural Engineering

(Soil and Water Engineering)

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM - 679 573

KERALA, INDIA

2017

DECLARATION

I hereby declare that this project report entitled **"Assessment of the Impact of Sand Mining on the Morphology of the Severely Affected Reach of Bharathapuzha River between Pattambi and Kuttippuram Using Remote Sensing and GIS"** is a bonafide record of research work done by me during the course of research and that the report has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Tavanur

Date: 24/10/17

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Certified that this thesis, entitled, **"Assessment of the Impact of Sand Mining on the Morphology of the Severely Affected Reach of Bharathapuzha River between Pattambi and Kuttippuram Using Remote Sensing and GIS"** is a record of research work done by Ms. Ardra Wilson under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, associateship to her.

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Acknowledgement

ACKNOWLEDGEMENT

I hereby wish to acknowledge my gratitude to all the researchers and practitioners who have contributed towards my understanding and thoughts. I sincerely thank all of them, friends, near and dear ones.

I avail this opportunity to express my deep sense of gratitude and heartfelt indebtedness to my major advisor **Er. Vishnu B.**, Associate Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur, for his proper guidance, benevolent criticisms and encouragement during the course of research work. His critical suggestions and comments was undoubtedly been the key for the successful preparation of this thesis work.

With extreme pleasure, I express my whole-hearted gratitude to **Dr. Santhi Mary Mathew,** Dean (Agricultural Engineering), Professor and Head of the Department of Food and Agricultural Process Engineering for her sustained guidance and encouragement.

I wish to pay tribute to **Dr. M. S. Hajilal,** Former Dean, K C A E T, Tavanur for his support that he offered while carrying out the research work.

I offer my special thanks to, **Dr. Rema K.P.,** Professor and Head of the Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur, as a member of advisory committee for her deemed support and guidance.

I am immensely thankful to **Dr. Anu Varughese**., Assistant Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur, for her enthusiastic support and sincere help during entire period of research work.

I remain thankful to **Er. Shivaji, K.P.,** Assistant Professor, Department of Farm Power, Machinery and Energy, K.C.A.E.T, Tavanur., as a member of advisory committee for his kind co-operation and scholarly advice.

With deep sense of obligation, I thank **Dr. Sasikala D.,** Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur, for her sincere help, support and co-operation for the completion of my research work.

I express my profound gratitude to **Dr. Asha Joseph.,** Associate Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur for her valuable suggestions.

I engrave my courtesy to **Dr. Sathian, K.K.,** Professor, Department of Irrigation and Drainage Engineering, K.C.A.E.T, Tavanur for his help and co-operation during the conduct of this research.

I wish to express my heartfelt indebtedness and deepest sense of gratitude to **Landmark Surveyors** for their kind help.

I express my profound sense of gratitude to **Er. Sheeja,** for her constant help, advice and invaluable support rendered during the conduct of research work.

I express my deep and sincere thanks to **Baburaj**, driver, K.C.A.E.T, Tavanur, for his support and timely help.

My completion of this project could not have been accomplished without the support of my classmates especially, **Er. Claudia K.L., Er. Vallu Tejaswini, Er. Gorla Gayathri, Er. Prvalika Y.R., Er. Tulluru Madhavi, Er. Pooja B.G. and Er. Sreekutty Suresh V.** I am indebted to all my seniors and juniors for their support.

I express my thanks to all the faculty **members of Library**, K.C.A.E.T., Tavanur for their ever-willing help and co-operation. I express my sincere thanks and gratitude to **Kelappaji College of Agricultural Engineering & Technology** for giving me an opportunity to undergo my P.G studies. My heartfelt thanks to **Kerala Agricultural University** in providing the favourable circumstances for the study.

I am thankful to each and every one who directly or indirectly helped me in doing this research.

I am in short of appropriate words to express my gratitude and love to my affectionate parents **Wilson** and **Ambika** and my brother **Adarsh** for their support, encouragement and prayers, ceaseless love and dedicated efforts.

Above all, I bow my head humbly before God Almighty for the grace and blessings bestowed on me.

ARDRA WILSON

Dedicated

to

God Almighty

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LIST OF SYMBOLS AND ABBREVIATIONS

/	:	Per
cm		Centimetre
DEM	:	Digital Elevation Model
ESRI	:	Environmental Systems Research Institute
et al.	:	and others
etc.	:	Etcetera
Fig.		Figure
GIS	:	Geographical Information System
GloVis	:	Global Visualisation Viewer
GUI	:	Graphical User Interface
IDE	:	Irrigation and Drainage Engineering
i.e.	:	that is
IRS	:	Indian Remote Sensing Satellite
KAU	:	Kerala Agricultural University
K.C.A.E.T.	:	Kelappaji College of Agricultural Engineering and Technology
km	:	Kilometre

km^2	:	Square Kilometre
m	:	Metre
m^2	:	Square metre
m/year	:	Metre per Year
N	:	North
NIR	:	Near Infrared
OLI	:	Operational Land Imager
RS	:	Remote Sensing
TM	:	Thematic Mapper
USGS	:	United States Geology Survey
UTM	:	Universal Transverse Mercator
WGS	:	World Geodetic System

Introduction

CHAPTER I

INTRODUCTION

Water is the essential building block of life. It is an indispensable resource for the social, economic and human development. Water is constantly circulating between earth's surface and the atmosphere up above in a never-ending conveyor belt called the water cycle. Rivers carry water from the higher parts of the earth to the lower parts. They form the corridors connecting the land to sea. Far from the oceans, rivers bring the land to life.

Rivers are the arteries of our planet; they are lifelines in the truest sense. They are the versatile features of the natural world that provide fresh water to people, plants and animals, and nourish both town and country. They have acted as cradles for civilization and agents of disaster; a river may be a barrier or a highway, it can bear trade and sediment, culture and conflict. Rivers, their floodplains, estuaries, and deltas had been the primary source of human development involving agriculture, transport, industry, waste disposal and settlement (Sreebha, 2008).

Rivers play a pivotal role in creating the world in which we live. They are the most prolific land surface sculptors. A variety of awe-inspiring landforms are carved out under fluvial processes. The science of carving out landforms by river action is called river morphology; a branch of geomorphology that deals with the form of the streams and adjoining areas as brought about by erosion, transportation and deposition of sediment by the running water (Garde, 2006).

In the nature, the most vital life sustaining system is the river. River channel, riparian zone, floodplain, and alluvial aquifer together forms the river system. River channel forms the most important component of the river ecosystem. Elements of river channel are planform, cross-sectional shape and channel slope which constitute the morphological characters of rivers. Rivers continuously change their shape and reform their channels by eroding the channel boundary and through reworking and deposition of sediments. Always an equilibrium is maintained between the energy of the flow and the resistance by the bed and banks. Spatial and temporal changes in the channel morphology are caused by the alterations in sediment delivery, hydraulic discharge, and channel slope. Changes in channels are even caused by tectonic uplift, erosion of the landscape and climate change. Human influences on channels causes drastic changes and leads to rapid destabilization of equilibrium conditions. Numerous human actions are endangering the very existence of the river itself. Among those actions uncontrolled sand mining had degraded the river and its adjoining areas to an irreparable level. (Padmalal and Maya, 2014).

Commercial extraction of sand from river sources is considered as global phenomenon. Mining had originated from the beginning of human evolution. Mining and agriculture were the fundamental activities that led to the development of civilized societies. Rapid economic growth and the resulting boom in construction has caused in mushrooming of river sand mining activities. Every year, 47 to 59 billion tonnes of material is mined from the whole world. Among that sand and gravel ranks the first. A conservative estimate of 40 billion tonnes per year of the world consumption of aggregates is twice the yearly amount of sediment carried by all the rivers of the world.

No source provides information regarding the usage of sand and aggregate within the country. Analysing the usage of cement and construction works; the amount of sand is calculated indirectly. It can be obtained indirectly from the usage of cement and construction works. Usage of cement is expected to reach 324 million tonnes, which accounts the usage of aggregates to 2.2 billion tonnes in India (GOI, 2015). The scenario is terrific in Kerala State, in the southwest coast of India.

The biodiversity and cultural richness of Kerala is nurtured by a great system of forty-four rivers. Rivers in Kerala are small in size with limited resources. These rivers have less net sand reserve compared to the rivers in neighbouring States. Indiscriminate sand extraction is expanding from early 1970's which is seen nearly in all the rivers and its adjacent river surroundings. During the period 2005–2006, about 30 million tonnes of sand had been mined from more than 2000 sand mining sites of Kerala rivers. From the studies conducted, it revealed that the river bed lowered at a rate of 5 to 20 cm per year (Sreebha, 2008). Among the rivers in Kerala, Bharathapuzha is one of the river severely disturbed due to sand mining.

Bharathapuzha, the second longest river in Kerala is also known as Nila. It has a total length of 209 km and a large basin of 6186 km^2. Nila is known as the basement of civilization in Kerala and it influences the Kerala culture to a great extent. Illegal sand mining is a common practice irrespective of all rules and regulations.

Auctioning and Permit System had made sand mining legal in the Bharathapuzha river. 48 kadavus of village panchayats is utilized for auctioning and 10 Government centres had received the permit. Illegal mining is carried out10 times of its legalised level. Studies showed that, amount of average sand mining was 2,88,000 loads which equates to Rs.13 crore but unlawful mining itself quantifies to Rs.200 crore.

Sand mining provides high government revenue as well as offers employment to local people which makes it a legal activity in Bharathapuzha river but indiscriminate sand mining is carried out beyond the legal limits. The day and night sand extraction had decreased the level of replacement of sand. Sand mining is still a major ecological danger in Kerala state, in spite of numerous prohibitions and regulations. Unscientific mining causes serious environmental problems to river ecosystems that which need immediate attention and corrective measures (Lakshmi and Zarrena, 2016).

Stream's physical characteristics, such as channel geometry, bed elevation, composition and stability, in-stream roughness of the bed etc had been directly affected by mining. Ecological equilibrium of the river system is badly affected by the change caused in the stream physical characteristics. It can cause harmful effects on in-stream biota and riparian habitats. It also causes changes in channel configuration and flow-paths (GOI, 2015). Channel stability is formed as a result of the balance maintained between river flow, channel form, influx of sediment from the watershed, and loss of sediment to downstream reaches. Disturbance in channel geometry causes channel instability due to instream mining. The two common methods of sand mining that causes bed degradation are pit excavation and bar skimming. Pit excavation increases the channel depth and bar skimming widens the river channel. Bank erosion and bank retreat are often seen in the river stretches undergoing indiscriminate sand mining. Over-mining is endangering the health of the river and the environment. Hence a better insight should be acquired by the society about various aspects of rivers to achieve better management of rivers (Padmalal and Maya, 2014).

Fluvial geomorphological surveys are highly popular during the last decade to support sustainable river management. Field-based approaches limits the wide-spread application due to the difficulty in data collection (Napieralski *et al.*, 2013). Study of various types of terrestrial based and aerial photographs, generated from satellite sensors for different time periods provides data to the geomorphologist to visualize, describe and to classify geomorphic attributes of rivers over a wide range of spatial scales.

River morphological data are decisive to researchers interested in the stability of rivers before authorising developments, ecologists concerned in fluvial disturbance and engineers interested with river training works. The objectivity and efficiency of river morphological investigations had greatly increased by the integration of remote sensing and GIS (Gilvear and Bryant, 2016).

Illegal sand mining is a common phenomenon in Bharathapuzha river, Nila of Kerala which is threatening the existence of the river itself. High rate of mining is carried out in the Kuttippuram to Pattambi reach of Bharathapuzha as it is almost shallow making it easy for the sand mafia to extract sand at a fast rate. As sand mining is a topic of political issue, field data collection has great risk and field methods are time-consuming and laborious. Rapid development in the field of Remote Sensing and GIS helps in this situation. Considering all the above aspects it has been decided to study the impact of sand mining in this particular region using remote sensing and GIS with the following objectives:

1. To evaluate the effect of sand mining on the morphology of the severely affected reach of Bharathapuzha River between Pattambi and Kuttippuram using remote sensing and GIS.
2. To assess the impact of sand mining on the river channel and the adjoining river banks.
3. To analyse the spatial and temporal variations of channel enlargement and lateral migration in the reach considered.

Review of literature

CHAPTER II

REVIEW OF LITERATURE

A critical review of the major studies conducted to analyse the impact of sand mining on the morphology of the river using remote sensing and GIS is presented in this chapter.

2.1 RIVER MORPHOLOGY

Water and sediment are transported by a river system. The river system exhibits the combined effect of the changes caused by the atmosphere and terrestrial systems. The physical form of the river system is created by the complex network of processes formed as a result of the exchange of dynamic forces between the sediment load and water and the hydrology and geology of the surroundings, while the river flows through its course. Fluvial geomorphology is defined as the interdisciplinary science that attempts to understand these processes and the process-form relationships in river systems. Specifically, fluvial geomorphology is "the study of sediment sources, fluxes and storage within the river catchment and channel over short, medium and longer timescales and of the resultant channel and floodplain morphology" (Newson and Sear, 1995).

"Fluvial morphology is also defined as the science of landforms produced by river action; a branch of geomorphology that deals with the form of the streams and adjoining areas as brought about by erosion, transportation and deposition of sediment by the running water". It deals with streams and stream systems, produced by the action of flowing water. The features produced on the land surface by flowing water is called fluvial landscapes. Morphology of streams changes as the erosion cycle proceeds. The three stages of development in the stream pass are youth, maturity and old age. The stream is less youthful near its mouth than in the head waters. In a newly uplifted land mass the first stage of the stream will be youth. It has steep slopes and the lateral erosion and valley widening is extremely small in this point. They are engaged in cutting channel downwards but may not have cut down enough. As there exists differences in hardness of the strata over which they flow frequent changes in slope of stream occurs. When the rate of down cutting decreases and the rate of lateral erosion increases the late youth ends and early maturity starts. Establishment of grade marks the passage from youth to maturity. At end of early maturity, V-shaped valleys and rapids and waterfalls disappear. Meandering activity is high in old stage which results in a greater width of floodplain. In the old stage there is pronounced meandering activity as a result of which width of flood plain exceeds several times the width of the meander belt. Oxbow lakes and swamps are usually formed as a result of cut-offs developed naturally (Garde, 2006).

Charlton (2008) defined "fluvial geomorphology as the study of the interactions between river channel forms and processes at a range of space and time scales". Through erosion of the channel boundary (bed and banks) and the reworking and deposition of sediments the rivers are continuously shaped and reformed. Channel widening is caused by erosion and undermining of the banks. Channel bed is deepened by scouring of the channel and channel bars were formed by the sediment deposition. Always a balance is maintained between the erosive power of the flow and the strength, or resistance, of the bed and bank material to erosion. During floods, dramatic changes in channel form occurs as the erosive power of the flow is greatly increased. These dramatic changes depend on the resistance provided by the bed and banks. Channel boundaries with high proportion of silt and clay are more resistant to erosion than with sand and fine gravel. Greater the amount and type of vegetation growing along the banks greater is the resistance to erosion. Extreme floods are only capable of modifying bedrock channels. Most flows have no effect on alluvial channels dominated with cobbles and boulders as they are not powerful enough to move such coarse material. Flow of water through the channel provides the energy needed to carry out geomorphological work. The flow discharge and the steepness of the channel slope are the two factors on which energy availability is depended. Stream power is increased with the increase in the above factors which finally increases the potential to carry out geomorphological work. A surprising amount of energy has to be used simply to move water through the channel before it is used for sediment transport and erosion. This amount of energy is used to overcome flow resistance and the friction between the flowing water and the channel boundary. Geomorphological work uses only 5 per cent of the river's energy, remaining 95 per cent of energy is utilised to overcome flow resistance.

2.2 IMPACTS OF SAND MINING

Aravindan (2002) narrated about the impacts of indiscriminate sand mining on the major rivers in Kerala. The major victims are the rivers such as Pampa, Manimala, Meenachil, Moovattupuzha, Bharathapuzha etc, which are exploited even after the ban is imposed by the Government. Ecological balance as well as social life is disturbed due to these uncontrolled mining. Illicit mining in the Bharathapuzha river is a habitual affair even though Bharathapuzha River Protection Committee had banned these actions. Government rules are futile in this case and still large-scale mining is carried at the river mouth. Ruthless extraction of sand had drowned the riverbeds, which weakened the bridges and dropped the ground water levels.

Pampa, Achancoil and Manimala, had been dried in numerous places during summer. Pampa had become a carrier of waste and banks of Manimala river had become unsuitable for crop cultivation. Illegal traders for sand mining are found in large numbers in those areas. Earth Science Studies documented that 4,66,400 cubic metres per annum of sand had been taken from the riverbeds beside a replenishment of 14,160 cubic metres. Unceasing sand mining had increased the river depth and collapsed the mud walls which caused threat to nearby houses and farms.

Deepa (2005) stated that sand mining prolonged rapidly on the riverbed of the Bharathapuzha even though numerous prohibitions and regulations existed. It had dropped the water tables significantly which had severely affected the rice production due to scarcity of water. The 209-km long river looks like an unkempt ground due to shrubs and weeds covered in most of the parts. Unbated sand mining over the historical time periods had destroyed the riverbed and deforestation minimized the river's catchment areas. The village of Chellur experiences shortage of drinking water normally from January. Palakkad suffered one of the worst droughts in 2004 in its history as the Bharathapuzha ran out completely.

Effect of sand mining had been dreadful for the river Bharathapuzha which was the source of drinking water to 175 villages in Palakkad, Thrissur and Malappuram districts, with a population of over 5.9 lakh in rural areas and 1.73 lakh in urban areas. Removal of sand cover had caused the sprouting of shrubs all over the riverbed and affects the velocity of the water flow. In summer, saline water enters the river easily. Sand mining had adversely affected the agriculture in Palakkad. Study conducted on the biodiversity of Bharathapuzha by Biju Kumar reported that cultivation of rice had been affected by the intrusion of seawater. Unbated sand mining had damaged the river's ecosystem as well, destroyed the environment of organisms living on the riverbed. Sand mining and the check dams constructed on the river had affected the fish breeding and migration too, it also affected many bird species such as egrets, storks, terns and sandpipers as it was the source of food. Sand mining is a great question mark over the very existence of the river and its ecosystem.

Santhosh and Sreeja (2012) depicted the evidences of the consequent impacts of the uncontrolled sand mining continuing in the river. In Kerala, sand mining is highly seen in the banks of river Bharathapuzha. Several studies had described about the destruction of riparian vegetation and the growth of exotic plants along the river basin of Bharathapuzha. Fish fauna in the river had been destroyed by the continuous sand extraction. the River bed in the downstream had lowered even below the sea level due to excessive sand mining. Extreme mining had disturbed the sand layers that hold considerable quantity of water. Percolation of water and ground water recharge had also reduced. Increasing the depth and width of the river bed resulted in depletion of groundwater and soil erosion throughout on the banks of the river. The next major issue was intrusion of saline water intrusion and scarcity of drinking water. Crack in the basements of pillars of many bridges due to sand extraction is a sign of the disastrous situation. Increased sedimentation had lessened the recreational potential of the river as well as increased the chances of side erosion.

Abubakar and Bashir (2013) examined the socio-economic implication of changes in channel morphology especially changes in channel width as it affects the production of crop in the adjacent land. The Channel width was measured on satellite images namely Landsat MSS Image of 1975, Landsat ETM Images of 1987 and 2005. Data on the socio-economic impacts of the changes were sourced from questionnaire administration. A total of 300 copies of questionnaires was administered to randomly selected respondents in the nine purposively selected riverine communities. The results revealed that majority of the respondents are engaged in land based economic activities, an average of 55.1% and 13.4% are engaged in farming and grazing respectively. An average 61% have their farmlands located less than 100 meters away from the channel bank, these along with other factors expose the respondents to impulses of changes in the channel morphology with losses in farm produce as a result of increasing incidence of bank erosion which causes channel widening.

Basavarajappa *et al.* (2014) highlighted the impacts of environment and its management in Cauvery and Kabini river basins of Mysore District, Karnataka. Efforts were taken to evaluate IRS-1D, PAN+LISS-III of False Colour Composite (FCC) through Visual Image Interpretation Techniques (VIIT) using GIS softwares to analyse the results. Sand extraction was permitted up to three feet, but it is being dug up even up to 25-30 feet which later fails the retaining irrigation wells. The river basins were seriously threatened due to excessive sand extraction which in turn affected the groundwater recharge.

2.3 STUDIES RELATED TO BHARATHAPUZHA RIVER

Bharathapuzha, the second largest river of Kerala is the lifeline of lots of people in the state, but now experiences terrific pressure because of invasions, sand and clay mining and illegal diversions of water. As the river is live only during monsoon season and in summer, there is no flow and this remains as one of the major issues of the river. The study was focused on measures for sustaining the river round the year with the specific objectives of modelling the topography of the river using GIS, studying the existing flow pattern of the river using simulation model and on the light of the study suggesting sustainable interventions to improve summer flow regimes of the river.

The entire catchment area of the river Bharathapuzha with 6186 km^2 was taken as the study area. Sub watershed delineation was the most important preliminary task involved in the whole exercise. For the quick and efficient delineation of micro watersheds, GIS and Soil and Water Assessment Tool (SWAT) were used. ILWIS and SWAT was used to delineate micro watershed and to conduct topographic analysis. The integrated GIS and image processing capability of ILWIS was utilized to prepare the Digital Elevation Model (DEM), drainage network, soil map and land use map for the catchment. SWAT was set up and calibrated for the basin with good simulation efficiency and the calibrated model was used to analyse the water balance of the whole basin and that of the individual sub basins. According to the detailed hydrologic analysis at micro level, appropriate interventions to improve the summer flow regimes of the river was recommended (Aiswaraya *et al.*, 2009).

Raj and Azeez (2009) examined the spatiotemporal variation in water quality and quantity of Bharathapuzha river basin using multivariate statistical analysis tools. Data of ten water years (1993–2003) on water quality were attained from five river gauge stations under the Central Water Commission (CWC; Government of India). Amparampalayam, Pudur, Mankara, Pulamanthole and Kumbidi were the chosen stations. The collected data was segregated and examined utilizing multivariate statistical techniques such as hierarchical cluster analysis (HCA), and principle component analysis (PCA). HCA was utilized to study the spatial variation in water quality as well as quantity among stations. The sub-basins showed variations in respect of river discharge, elemental concentration and elemental load. It was found that, monsoonal discharge was higher in basins that are more disturbed whereas the basins are slightly disturbed had consistent level of discharge throughout the season. Spatiotemporal changes in the surface water chemistry of the river is caused by the changes in land use and the impact of dams.

A study had been carried out on Bharathapuzha, focusing on implementation of check dams for improving summer flow regimes of the river. The study aimed at improving the yield of Kunthipuzha, one of the tributaries of Bharathapuzha. It has a catchment area of 822.22 km^2. Micro watershed delineations and topographic analysis were done using ILWIS and SWAT. Digital Elevation Model (DEM), drainage network, soil map and land use map for the catchment were prepared with the help of ILWIS. SWAT was put up and calibrated for the basin with good simulation efficiency and the calibrated model was used to analyse the water balance of the whole basin and that of the individual sub basins. Model's predictive capability was evaluated using the statistical measures of NSE and COD. When number of check dams were incorporated, the base flow contribution showed a significant increase during summer months and it resulted in considerable enhanced yield of the basin. Daily, monthly and annual basis graphs showing the comparison of with and without simulations along with 24 and 50 check dams were plotted for different years. Approximately an increase in discharge of 0.32 m^3/s during summer months was obtained when a total of 50 check dams were added. Further research can be conducted to optimize the number and location of check dams. These studies can be extended to other river basins of Kerala too (Arshana *et al.*, 2010).

Since 1989, Wadakkancheri region has been identified as a site of micro seismic activity. The right-angled turn of Bharathapuzha River at Desamangalam and a waterfall near this structure shows the influence of the structure to the drainage system which is identified as a south dipping reverse fault. SRTM data was used to identify the network of paleochannels. The influence of fault on the drainage system of the area was analysed using distance elevation profiles drawn from SRTM data. Paleochannels and the river flows approximately at the same elevation near the coast. A marked correlation between channel morphology and the proximity of the fault in the Bharathapuzha river basin was exhibited by the data generated in the study. Shuttle Radar Topography Mission (SRTM) data with a spatial resolution of 90/90 m was used to identify these signatures from topography. ERDAS was used to crop the study area from the data. ArcGIS was utilized and contours were generated for an interval of 20 m. 3D analyst tool of Arc GIS was applied to generate Triangular Irregular Network (TIN) from the contours. Distance-elevation profiles were drawn across the mapped faults that were projected in the DEM. Hydrology Tool of ArcGIS software had been used to identify paleochannels as well as present channel hydrogeological modelling. Quick evaluation of active faults had been carried out using SRTM data. Along the vicinity of the fault the drainage flows through a wider valley compared to the region where the faults do not have any influence. The present study indicates that Bharathapuzha river is controlled by the faults in the study area (John *et al*., 2013).

Climate change impact studies are carried out with the help of hydrologic models. Proper bias correction in the climate data is required to operate the hydrologic models. In the present study comparing downscaled re-analysis data on precipitation and temperature from five regional climate models (RCM's) derived from different Global Climate Models (GCM's) with observed data of Bharathapuzha river basin, Kerala, were compared based on the four statistical parameters (standard deviation, correlation coefficient, coefficient of variation and centred root mean square difference) to find out the best suitable climate model. Meteorological data including daily precipitation and maximum and minimum temperatures for the period 1971-2005 were collected from the observatories located in the area and this was taken as the reference period. The periods 2041-70 and 2071-99 in this study were considered as the two future scenarios. An appropriate RCM was selected by comparing the outputs of Regional Climate Models (RCMs). Power transformation was used to correct the bias in precipitation as it corrects the mean and coefficient of variation (CV) of the observations. Fitting the normally distributed temperature to mean and standard deviation of the observations was corrected. Comparison of the post-processed climate data to observed climate data was carried out. Observed data of Bharathapuzha river basin on precipitation and temperature during the reference period and historical data from 5 regional climate models were compared. The four statistical parameters (standard deviation, correlation coefficient, coefficient of variation and centred root mean square difference) were used to evaluate the similarity of the data sets with the observed data. RCP 4.5 and RCP 8.5 were the two emission scenarios pathways selected for the study which roughly correspond to the Special Report on Emission Scenarios (SRES) B1 and A1F1 respectively by 2100. CORDEX simulations were analysed to identify the probable changes of surface climate over Bharathapuzha river basin. Downscaled re-analysis data on precipitation and temperature from five regional climate models (RCM's) derived from different Global Climate Models (GCM's) were compared with observed data based on statistical parameters. GFDL-CM3 RCM had good comparison with the observed data. So future predicted data of the model had been used for further data analysis after doing bias correction. It was found that there may be a consistent decrease in rainfall during all months except May, August, September, November and December by analysing the result of comparison of the monthly variation of bias corrected data of precipitation for the two emission scenarios (RCP4.5 and RCP8.5) for the periods 2041-70 and 2071-99 with observed data. A decrease of 4 per cent to 7 per cent in average annual rainfall during 2041-70 and about a tone of 10 per cent to 15 per cent during 2071-99 was predicted. A significant fall in the southwest monsoon and rise in the northeast monsoon showed a seasonal shift in the rainfall pattern. An increase in the annual maximum and minimum temperature in the basin in the future was also predicted under both scenarios. The results obtained can be utilised in formulating future water resources management plans and for assessing the impact of climate change in the area using hydrologic models (Varughese, 2016).

2.4 ROLE OF REMOTE SENSING AND GIS

Systems that are complex and dynamic and complex with varying flow properties and landform assemblages constitute the streams and fluvial environments. Remote sensing methods and digital data are highly useful for the fluvial geomorphologist to analyse and map the temporal and spatial scaling of rivers and calculate river shape, process, and rates of morphological change. Photographic and digital stereo imagery reveal the topographic variation by producing 3D perceptions on fluvial environments. Channel width changes and sinuosity are extracted from single or mosaicked photos by qualitative interpretations. Aerial photography assists in plan-view measurements of bank full width, river sinuosity, and lateral channel migration. Temporal sequences of aerial photos provide the baseline data for stream management and examination. Relationships between stream dynamics and landform evolution had received great insights with advances in sensor technology and data availability. Fluvial features such as stream networks, watershed boundaries, flow accumulation grids, and nodes or confluences can be derived from DEM's. Software programs for example Hydro toolbox in ArcGIS, IDRISI, River Tools perform functions related to stream research. To measure river-system behaviour at various spatial and temporal scales the advancement in remote sensing and GIS is utilized. Remote surveying is the only practical technique for monitoring and mapping river environments (Napieralski *et al.*, 2013).

Fluvial geomorphology had focussed on two-dimensional mapping of river channel morphology and its change since decades. The availability of Google Earth opened a unique innovative resource for two-dimensional mapping of channel morphology and floodplains. The issue remains with the scale of remotely sensed data. A wide range of scales were available to observe the large channels on satellite data. The constraint that restricted was the river length on large scale images which resulted high purchase cost and time. Spatial resolution was critical for smaller channels. Visual interpretation makes clear the channel position, however small changes is precisely measured by applying geometric rectification. Since the 1970s, change in channel planform of large river systems had been visualized with the enhanced knowledge provided by satellite data. Different methods are needed to quantify the channel morphology of submerged and exposed areas of the river. Large-scale aerial photogrammetry had been used to produce accurate elevation data for exposed channel bars. Laser altimetry maps the change in morphology of exposed channel beds from sequential datasets. To derive water depths a robust technique was applied for image analysis on aerial photographs. The results of studies related to water depth had been proved to be relatively accurate in comparison with ground-truth data collected. (Gilvear and Brayant, 2016).

2.5 MONITORING AND ASSESSMENT USING REMOTE SENSING AND GIS

Alam *et al.* (2007) studied on the change in river morphology of old Brahmaputra and its social impacts using remote sensing. Landsat TM data of 1997 and 2000 had been used for the study. ERDAS IMAGINE software was used for the unsupervised classification of image data. Thresholding is applied to separate land and water and to extract river feature from the satellite images. After land water classification images are overlaid and the changes are detected. Analysis of the images showed that significant change had been happened in north east part of Mymensingh Sadar Upazila and the change was found to be less in the lower part that close to the Mymensingh town.

IRS P6 LISS III data and GIS was utilized to find out the factors affecting the sinuosity of the Pannagon river. Data used for the study were satellite and topographic data, geological maps and field investigations. These data were examined to know the effects on the morphology of the river. SOI toposheet provided the base information about the study area. Satellite data provided the thematic information regarding lithology, structure, geomorphology, slope and field data gave information on riparian vegetation and hydrology. AutoCAD Map 2000 was used to digitize the thematic maps and further analysis was carried out in a GIS environment. The method of overlay analysis in the GIS was used to identify the effect of various aspects over the river sinuosity. The sinuosity index was calculated based on the selected three segments. The calculated sinuosity index of the selected segments in the river were 1.6 and 1.8 in the years 1967 and 2004 respectively. The study showed that the lower reaches of the river contains more sinuous patches and most of the area lies under floodplain. The major factors influencing the degree of sinuosity were the geological factors (Aswathy *et al.*, 2007).

Buckingham and Whitney (2007) examined the consequences of accelerated urban expansion on a hydrologic system of Las Vegas Wash over a period of 24 years from 1975 to 1999. Three aerial photosets of 1975, 1989, and 1999 were used in the GIS analysis. The photosets were ortho-corrected and geo-registered. Active channels were digitized. The DEMs were overlaid based on the change in area and calculated the total amount of sediment removed from the channel. A tool in GIS was utilized to map all the areas near the active channel that experienced change. Mapped areas resulted the erosional area. Polystats was used to calculate channel width. Study revealed that channel shifted laterally across the valley floor during the past 24-years. The spatial analysis quantified channel changes for discrete time periods and calculated the erosion volumes.

Mohammadi *et al.* (2008) conducted a study to determine the changes in morphology of Dough river, Iran utilizing GIS. River morphology had been changed by the human and the geological, topographical and climatological impacts. Utilizing the longitudinal and cross section maps morphology of the 13-km reach had been studied. Satellite images were enhanced by applying geometric corrections, radiometric corrections and georeferencing. Finally, colour composite (RGB) was created. The morphological parameters of the Gorgan River such as sinuosity length, meander length, width of meander belt, average curve radius, amplitude and sinuosity coefficient had been measured and calculated using AutoCAD 2006 software. It was revealed that the number of meanders had an increment from 22 to 28 and the meander coefficients changed from 3.21 to 3.47 respectively.

Eljack *et al.* (2010) examined the issue of sand infringement and their natural effect on the Nile River morphology. The information chose for examination were cloud free LANDSAT MSS, TM and ETM+ scenes. A broad field review was performed all through the examination range utilizing GPS hardware. This review was performed keeping in mind the end goal to get exact area point information for each land cover class incorporated into the characterization plot. MSS 1972 and TM 1987, were geometrically co-registered to the rectified ETM+ 2001 information. Georeferencing was given by choosing and applying ground control points (GCPs). Nearest neighboring method was utilized for georeferencing. The diminished sand dune (1987-2001) could be ascribed to an expansion in the region secured by river course because of heavy flood during 2000.

Ghoshal *et al.* (2010) performed a study to analyse the channel and floodplain change occurred during a period of 100-years in lower Yuba river, California. Picture information utilized for the examination were historical maps, aerial photographs, DOQQs, SONAR and PDTD. DEM differencing and planimetric change examination were the techniques used for the investigation. Planimetric changes and rates of channel migration for the lower Yuba Rivers were mapped using aerial photographs, orthophotos, and historic survey maps. Adobe Photoshop 7, Macromedia Freehand 8 programming, ArcGIS 9.2 and ERDAS Imagine 9.2 were the product's utilized for image processing and examination. Differencing of 3 × 3-m topographic information demonstrated considerable channel morphological changes and recorded 12.6 × 106 m^3 of erosion and 5.8 × 106 m^3 of deposition in these areas from 1906. Planimetric and volumetric estimations reported that channels deepened up to ~13 m.

Quantitative and qualitative river morphological analysis had been carried out with the help of tools provided in remote sensing and geographic information system. The study was aimed at analysing the channel migration of the Padma and the Jamuna rivers using remote sensing and GIS during the time period 1977 to 2004. Padma and the Jamuna are the two major rivers in Bangladesh. In this study cloud, free Landsat images of four scenes for dry season were used. PCI Geomatica was used for image processing and ArcGIS 9.3 for GIS analysis. Visualizing the Landsat images nine locations were identified as spots to investigate the channel migration. Based on the erosion rate these nine locations were selected. The images were classified as water and nonwater body. These classified images were transferred into GIS layers using ArcGIS 9.3. Movement of river channel was measured using a standard measurement tool of ArcGIS based on initial river channel in 1977. During 1977-2004, confluence point of the Padma and Jamuna (at location E) migrated about 9000m toward southeast. Channel of the Padma river had a faster rate of confluence point migration (Islam, 2010).

Kumar *et al.* (2010) carried out a study on the application of remote sensing and geographic information system in change detection of Netravati and Gurpur river channels, Karnataka, India. The data products used in this study were topographic maps of 1910 and 1967, IRS 1C/ P6 and LISS-III, 23.5 m resolution images of 1997, 2001 and 2005. The satellite images were geo-referenced using more than 50 ground control points (GCPs). Nearest neighbour interpolation method was utilized to rectify the images into UTM Zone 43N with WGS 84 as datum. ArcGIS v. 9, Surfer v. 9 and ERDAS Imagine v. 9 software were used to perform the overlay analysis of multi-temporal topographic maps and satellite images and to determine the nature and amount of shift in the river channels. The study revealed that the channels had reduced its width and shifted to south in all the three blocks, during the period considered.

Tien and Hau River had experienced genuine disintegrations with normal speed from 5 to 30m every year in Hong Ngu and Sa Dec District in Dong Thap Province and in Tan Chau and Long Xuyen District in A Giang Province. This had genuinely influenced the life of nationals. Hence, investigation of changes in the riverbanks of Mekong stream - Vietnam by utilizing multi-transient remote sensing information was directed to anticipate the future changes in the riverbanks. Landsat MSS, TM, ETM+, ASTER, and ERS-2 images from 1989 to 2009 had been utilized for the examination. Topographical maps of the range were utilized to give the base guide from 1966-1968. Rate of changes in next 5 and 10 years was predicted using the Digital Shoreline Analysis System (DSAS) software. The satellite data collected was geo-referenced and the riverbanks were extracted by digitizing. DSAS module running in ArcGIS environment took digitized vector lines as input. At that point MATLAB program took these directions as contribution to run linear regression to conjecture what will occur between the years 2015 and 2020. Results demonstrated that riverbanks in Sa Dec District are anticipated to be disintegrated at a rate of 50 m every year until 2015 and 2020. An overall erosion from 100 to 520 m in next 10 years was likewise anticipated. Adjacent to the disintegration, gradual addition had additionally occurred in the Cape of Thuong Phuoc right side of Tien waterway with the rate around 17-20 m for each year and anticipated to be accumulated 108 m in 2015 and 171 m in 2020 (Nguyen *et al.*, 2010).

One of the major rivers in Murshidabad district is Bhagirathi River. The changes of the river were analysed by comparing the images of the river during the year 1970, 1977, 1990, 2000 and 2006. Landsat images, toposheet, Google earth map and block map images were collected for the study area and were rectified using ERDAS IMAGINE –9.0. Images were registered and subseted to depict the study area utilizing ERDAS IMAGINE –9.0 and ArcGIS –9.2. Water body was masked from the subseted images and the stream was digitized using toposheet and Google map in ArcGIS –9.2. Superimposing the pictures and digitizing every variation were recorded It was seen that huge change had been happened in southern piece of the waterway and less change was found in the center part. Water discharge, soil types and transportation of sediment is the major contributing component of morphological. Most extreme disintegration occurred at Dear Balagachi. Baidyanathpur experienced a cut-off in 1984 (Panda and Bandyopadhyay, 2010).

Uddin *et al.* (2011) evaluated the morphological changes and vulnerability of stream bank disintegration nearby of the waterway Jamuna utilizing RS and GIS methods. Evaluation had been done utilizing 2010, 2003, 1989, 1980 and 1973 years Landsat ETM+, TM and MSS images and settlement was distinguished utilizing topographic maps of 1947. Images were georeferenced and projected into UTM Zone 45 based on Ground Control Points (GCP) from Landsat ETM+ (2003). Nearest neighbour method was used for resampling and resampled to a common resolution of 30m. River channel mapping was performed using eCognition/Definiens object based image and ArcGIS was applied to obtain accurate information on recent river channel movement and bank erosion. For further processing the classified data was exported to shape file format. The study enumerated that rates of bank erosion and siltation was very high and was about 1235.25 km^2 and 29.82 km^2respectively. In the year 2003 river moved about 35847 m and about 16415 m in the year of 2010.

River change detection and bank erosion identification of Pravara river, India using topographical and remote sensing data was done by Aher *et al.* (2012). Topo map, google earth images and SRTM data had been used for the study. Images were rectified, digitized and superimposed in the GIS software Global Mapper8 to analyse the change in river and in bank erosion. The study revealed the changes occurred during 35 years from1974 to 2009. Analysis showed that river bank shifted in both sides due to manmade and natural activities.

Topographical sheets (1943 and 1969-72), IRS LISS III (2001), Landsat MSS (1970, 72 and 73), ETM+ (2000) and TM (2006) images were utilized to locate the areas with continuous erosion and deposition in different sections of Damodar River (Rhondia to Paikpara). The stream Damodar consistently adjusts its path that recreate the morphology of the valley and create Quaternary floodplain facies. Three topographical maps were set up to assign the temporal changes of both side of Damodar River to indicate the erosion and deposition of dynamic valley in different destinations. For the examination the two banks and channel are digitized from Landsat MSS and TM in three vector layers and in the wake of overlaying those pictures last output maps were made. The micro-level changes in the spatial and temporal attributes of Damodar River were discovered and evaluated by the combination of GIS, remote sensing, and quantitative geomorphology. The present investigation uncovered that the stream in the middle of Rhondia and Barddhaman demonstrates deposition, braiding and valley widening whereas downstream of Barsul up to Paikpara with bank erosion, high sinuosity and narrowness (Ghosh, 2012).

Gogoi *et al.* (2012) conducted a study utilizing Remote Sensing (RS) and Geographical Information System (GIS) upper part of Assam valley, NE to outline the two essential fluvio-morphological changes that happened in the junctures of Dihang, Dibang and Lohit waterways and furthermore decided to determine the increase in valley width of the River Brahmaputra. TM+ and MSS satellite imageries of year 1986 and 2011 was utilized to conduct the study. Water bodies, drainage, channels networks were traced as vector layers utilizing Global Mapper v.11 from the satellite imageries. Capturing of river diverted the main stream of Lohit river along Dangori river within the period of 25 years from 1986 to 2011. As an outcome of this disparity, the conversion purpose of Dibang and Lohit waterways at upper east of Dibrusaikhowa, moved towards south of Dibrusaikhowa by around 59.76 km in valley length (territory around 54 km). River migration caused a total loss of 846 km^2 and river enlargement was up to 86 per cent of the in 1986. The normal bank line migration rate was around 115 m/year in a few areas.

Horn *et al.* (2012) displayed information incorporated from airborne photography, General Land Office maps (GLOs), and discharge data from the central Platte River in Nebraska that evaluated and give another comprehension of desertion and channel evolution in a braided stream. Utilizing ArcMap™ the FSA aerial imagery was scanned, georeferenced, and overlaid on DOQQs. Every layer was analysed by computing, measuring channel cross segments each 100 m, and by looking at the vegetated and unvegetated lands based on the imagery taken amid past and ensuing years. Studies demonstrated that 46 per cent of channel area was decreased from 1938 to 2006 width of decreased about 539 per cent in the year 2006 than in the year 1938 based on the analysis of aerial photographs and GLOs in ArcMap™.

Samanta and Pal (2012) proposed an empirical methodology for mapping and analysing the channel morphology utilizing remote sensing and GIS systems. IRS 1D LISS III; LANDSAT MSS and ETM+ and Cartosat-1 satellite data were used along with field survey data. Different cross-sectional data of river bed elevation were collected across and along the Kasai river. Study had been conducted to create and analyse the land use/ land cover characteristics of the flood plain, erosional and depositional characteristics of river bed and river bank, changes of channel morphology, the human impact to change the channel morphology of Kasai River in Paschim Medinipur. A close analysis of channel orientation of River Kasai showed a prominent variation in the channel pattern during the period of analysis 1976 to 2005. An abrupt change was found in channel pattern between topographical map and 1998 image, that showed channel was shifted from north to south between the extension of 87° 16′ 30″ E to 87° 17′ 00″E and 22° 24′ 30″ N to 22° 25′ 00″ N. In comparison of two satellite images 1998 and 2002 it was found that the meander of east portion of the study area, became straight line. The river had developed its course on the basis of the lithological characteristics of the region. The river channel in the study area had changed its path during 1998 to present day. A comparative study was done to show the evaluation of meander from 1998 to 2002 for the study area.

Sarkar *et al.* (2012) conducted an assessment of river dynamics of Bhramaputra river, India utilizing RS-GIS. The study measured the bank deposition and erosion along the Brahmaputra river for eighteen years (1990-2008). IRS 1A LISS-I, and IRS-P6 LISS-III satellite images of 1990 and 2008 were utilized to map the channel configuration. ERDAS Imagine 9.3 was utilized to process the images. River bank data was analysed using ArcMap 9.3. The satellite images were georeferenced using Landsat ETM images. Radiometric normalization was applied to georeferenced images and then they were mosaiced together. NDWI image had been prepared using Normalized Difference Water Index which was utilized to delineate the river water course. Using ArcMap software, the left river bank (south) and right (north) banks had been digitized. River bank lines for the years 1990 and 2008 had been prepared. Area estimation using GIS software tools had been utilised to calculate the erosional and depositional area for polygon areas with the shifting bank-lines in study period. The present work had showed acute the fluvial changes in current years causing significant land loss in the river reach.

An examination identified with stream elements was directed by Chakraborty and Datta (2013) in the lower course of Diana River in the Jaldhaka-Diana river system, West Bengal. The spatio-temporal sequences of changes in channel, resulting development of conversion point and the variables and reasons for such development were uncovered utilizing multi-temporal topographical maps and satellite images for a period spreading over almost 80 years (1930– 2011). Temporal variation of channel position along with channel bed and banks as well as confluence points were analysed using three sets of Topographical Maps for the years 1929–30, 1964–65 and 1969-70. The satellite images obtained in between 1991 and 2011 from Landsat 5 TM and Landsat 7 ETM+ had been analysed to evaluate the effect of the several floods that occurred during the recent times. Landsat 7 ETM+ had been enhanced and compared with topographical maps of earlier periods. Satellite imagery from Google Earth were also supplemented. All temporal data were registered in ERDAS Imagine software for image processing. Further processing had been carried with ArcGIS software for final product generation. Data were rectified, enhanced and applying edge matching technology, spatio-temporal shifts of confluence points were obtained and mapped in the GIS environment. For extraction, base map had been generated from SOI Topographical maps and satellite images. It had been induced that amid the span of study the confluence point had moved and re-situated both upstream and downstream on a verifiable period and new confluence points had been made by repeated shifting and migration of channels.

Cunliffe (2013) examined the planform changes in the River Liza, Ennerdale, Cumbria all through 1867 – 2009 using historic and contemporary maps and aerial imagery. Analysis had been done in ESRI's ArcGIS desktop (V.10). Map tiles were mosaicked, and re-projected. To empower quantitative correlation, images were registered to the latest OS 1: 10,000 map. Co-registration was attempted utilizing 10-24 ground control points (GCPs) disseminated for optimal warp stability on each dataset, utilizing OS mapping grids and man-made features. On-screen digitization method was applied to obtain channel boundaries as vector polygons. Production of channel occupancy maps and qualitative assessment were carried out. Planform investigation uncovered various spatiotemporal attributes of the fluvial system, in spite of the fact that inferences are significantly debilitated by uncertainty.

Dabojani *et al.* (2013) utilizing Remote Sensing and Geographical Information System (GIS) computed the shift in the banks of the Manu River in Bangladesh that occurred between 1997-2010. The channel alignment of the Manu River had been plotted using Landsat satellite images. The software ArcGIS 9.3

was used to investigate the images. The collected satellite images georeferenced and the riverbanks were digitized. The river area was demarcated from the images using ArcGIS 9.3. Polygons of different years were digitized on each location reach. Amount of River shifting, Bankline migration and direction of the shifting were then calculated using ArcGIS tool. The investigation uncovered that the Manu River is a profoundly winding waterway with a few basic areas where the stream had been enduring massively with the disintegration issue and shifting characteristics. disintegration issue and moving attributes. The most extreme left bank movement happened at Rajnagar was about 656 m and greatest right bank movement at Moulvibazar was about 628 m in the specified time.

The Subansiri stream frames one of the biggest among the Trans-Himalayan tributaries of the Brahmaputra River in Assam. The Subansiri stream is portrayed by ceaseless channel morphological changes, bank line movement and horizontal channel changes which additionally creates serious bank disintegration prompting a significant loss of good prolific land each year. The satellite image of IRS LISS-III of 1995 and Landsat 5 TM of 2010 utilized for the examination of flow pattern changes in the river. The data's were georeferenced utilizing GIS programming ARCGIS 9.3. Georeferenced satellite imageries were used to digitise the bank lines and then the bank lines were overlaid. The pattern of channel migration and the rate of deposition and erosion was found out from the overlaid bank lines. The moving of the stream implied moving of the bank line towards eastern or western side Study demonstrated that the width of the Subansiri stream through Ghagar nala had expanded in the considered time period because of disintegration along the two banks of the waterway. The 82.089 km^2 of erosion and 43.231 km^2 of deposition was seen along both banks of the Subansiri river. (Gogoi and Goswami, 2013).

Pan (2013) performed a study on the analysis of the changes that occurred in the drainage system of Bankura district, West Bengal using remote sensing and GIS. Topographical maps, Landsat MSS and ETM+ of different dates and the google earth image of 2011 were examined utilizing RS-GIS software. Satellite data were georeferenced and the river course were digitized from the images. The analysed results are then overlaid on each other and the change in cross valley asymmetry, sinuosity index, entrenchment ratio and shift in the thalweg were determined.

The Subansiri which is the major Trans Himalayan tributary of the River Brahmaputra is a highly changing alluvial channel in Assam. The study had been conducted for the period from 1828 to 2011 and the trend in the shift of channel and other changes of the Subansiri river had been analysed. Survey map SOI toposheets, Landsat MSS, TM, ETM+ and IRS LISS 3 of 20 different years and available literature on the Subansiri river were the data used for the present study. Toposheets and satellite images of the study area for different years had been georeferenced with WGS84 datum to UTM projection. The bank lines had been digitized. The trend of channel migration during 1828 to 2011 of the Subansiri river was obtained by overlaying the digitized bank lines. Avulsion, alternate bar induced shifting, meander shift, chute cut-off, and neck cut-off were the five different types of channel shift that had been seen in the Subansiri river. The change in trend of channel of the Subansiri river in Assam was caused by the abandonment of large number of channels. River had migrated by abandoning the earlier channels from east to west of the basin. The migration was caused by the instability created by huge sediment load and heavy discharge during floods (Gogoi and Goswami, 2014).

Hossain *et al.* (2014) conducted a study to analyse the GIS based morphometric activities of the Meghna catchment, Bangladesh. The methods of assessment selected were field visit/visual inspection, data analysis, satellite image interpretation, analytical assessments and mathematical modelling. Velocity of the stream and area of cross-section and GPS points were obtained from four locations on the Meghna stream, and one of the stream's section was mapped utilizing a GPS. ArcMap 9.3 software was used to process the data collected and to generate several maps of the study site and some velocity profiles. The velocity profiles gathered from the study was used to understand the stability of slope to predict the changes in the geomorphology of the stream which would occur in future. Bathymetry data of seven river cross sections of Meghna river had been obtained from BWDB for the years 1998-99 and 2000-01 respectively. Satellite images of the year 1980, 1989, 2000 were superimposed on image of year 2010 to obtain the bank lines for planform change analysis. The recent and consistent data on the dynamic geomorphology of the Meghna River for creating and executing the drainage development programs and erosion control schemes in the Meghna flood plain region of Bangladesh was obtained from the study.

Jamuna River is a 240 km long braided river which lies in the lowest reach of the Brahmaputra River in Bangladesh. Jammuna river exhibited consistent lateral migration due to large discharge and heavy sediment load which resulted in erosion of the river banks. A study was conducted to find out the trend and coverage of channel migration and erosion of bank in the river using satellite imagery and old historical images. Study resulted the susceptible segments of the river affected by bank erosion. Data used for the study were the Landsat images from 1973 to 2014. Satellite imageries were geo-referenced and bank lines were digitized using ArcGIS. GIS software was used to estimate the pattern of deposition and erosion caused by the lateral movement of the river channel. Study also resulted the pattern of channel migration of the highly morphologically active river (Khan *et al*., 2014).

Madhavi (2014) examined the morphology of a river by considering its long profile and cross profile. The present study had been carried out on the river Ganga at Varanasi for calculating amount of meandering in the form of change of sinuosity at two consecutive bends. For the research 10 years of satellite imagery data had been analysed using ArcGIS combined with historical data. Air photo prints were georeferenced in ArcGIS 9.1. The ground control points (GCPs) utilized for rectification were gathered through GPS from the field or collected from topographic maps. Images were georeferenced utilizing the GCPs. Channel lines were digitized utilizing the water boundary to depict the edge of the channel. The outcome demonstrated that sinuosity fluctuated from 1.66 to 1.26 and sediment deposition of two bends shifted from 4.52 to 3.14 and 3.4 to 2.42 separately.

Qi *et al*. (2014) examined the morphologic change caused by sand digging in Poyang Lake bowl by overlaying two DEMs procured in 1952 and 2010 individually. This investigation is valuable to comprehend the difference in hydrological system, particularly the drying up pattern in Poyang Lake in late falls and winters. Dredging vessels was distributed in the sand mining region as a cover to assess the dug sand volume amid 2001-2010 by applying the cut hill function in ArcGIS 10.0 on the two overlaid DEMs.. Sand dug from Poyang Lake was around 1.99×109 m^3. It implied that the size of sand mining amid 2001-2010 was very nearly 10 times of sand depositions in Poyang Lake amid 1955-2010. Results emphasised that sand dredging in Poyang Lake has changed the lake capacity and discharge section area and the course of river in the northern channel was extended by above 1 km when in low lake level.

The present research showed results on river morphology of Red river by remote sensing data analysis and comparing and verifying with real observation result and some existing maps. GIS software was utilized to analyse data and administrate the study area maps. TM, ETM+ sensor of Landsat satellite and Landsat 8 images of four different years were used for the study. ASTER image, ALOS image, fieldwork data, topographic map were used as additional data. The data were pre-processed by applying ratio correction and geometric correction steps. Post classification comparison, direct classification, image differencing and combination steps were applied as the change detection steps. The results showed that phenomenon deposition varies with year and during different stages of a year (Truong *et al.*, 2014).

Stream channels have a tendency to adjust and move because of both anthropogenic impacts and ceaseless common changes in condition. The potential migration river channel zones and degree of evolution in past were assessed. River width, braid-channel ratio, river sinuosity and riparian vegetation were the features analysed to assess evolution. Multispectral images of Landsat-5 TM and Landsat-7 ETM+ of thirty years (1990-2010) were analysed to assess the morphological changes. Satellite images for years 1990, 2000 and 2010 were obtained and stacked. Collected rectified data was projected to Universal Transverse Mercator (UTM) system. QUAC (Quick Atmospheric Correction) model was applied for atmospheric correction. Land cover categories within satellite images were classified using density slicing. In band 7 water class threshold range was for every one of the three years and after that removed as a single class, then it was changed over into format of shapefile for further processing. Indices approach was utilized to assess stream properties utilizing RSI"s ENVI ™, Leica Geosystem's ERDAS Imagine ™, ESRI"S ArcMAP™, MapInfo™, and Global Mapper™, The U.S. Topographical Survey's DSAS™, and Hawth's tools ™. recognized in view of information from 1990 to 2010 and it was discovered that significant potential waterway movement zones are at Indus river in Rajanpur region, Chenab stream in Muzzafargarh and Jhang area, while every single other zone were seen to fall in slightest potential movement zones. River width, braids-channel ratio, river sinuosity and riparian vegetation were the other attribute calculated to discover the experienced changes (Anam *et al*., 2015).

Jiadhol river system is one of the most dynamic rivers flowing out of the foothills of Himalaya in Arunachal Pradesh and joining mighty Brahmaputra in Dhemaji district of Assam. This river had created flood havoc in the District of Dhemaji due to frequent avulsion over the decades. This study was aimed to analyse the pattern of channel avulsion in the Jiadhol River. The data on channel position of the river at different time were extracted from the toposheets of Survey of India 83 I with RF 1:50,000 surveyed between 1963 and 1967. Satellite imageries were downloaded from the USGS Earth Explorer. Landsat TM, ETM and MSS were the images used. The river Jiya Dhol was digitized in ArcGIS 9.3 Software using landsat images and analysed the phenomenon of channel avulsion of the river. The analysis showed that the most drastic avulsion took place in between 1963 to 1973, the course of the river shifted from west to east by approximately 12 km. The distance of avulsion was largest in the period between 1963 and 1973 and the trend of avulsion was west to east. The distance of avulsion had decreased over time and the trend of avulsion was east to west form 1973 till 1993. The distance of avulsion had further reduced in recent time and the recent trend was again from west to east. The rate of avulsion was high for the studied that was less than ten years for most of the time. The understanding of the trend of channel avulsion helped in proper flood management of the basin (Das, 2015).

Yang *et al*. (2015) did the trajectory analysis of channel migration in lower Jinjiang reach of China during the time periods 1983-2013 using remote sensing techniques. In China, the Lower Jingjiang Reach (LJR) of the Yangtze River is a standout among the complicated regions as far as channel migration. Satellite imageries of Landsat Multi Spectral Scanner (MSS), Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) were the data sets utilised to calculate the planform migration of the reach from 1983 to 2013. Bank lines were extracted from the images using NDWI (Normalized difference water index). Planform change characteristics were depicted by measuring the average width and length, water surface area and sinuosity. The spatial difference of channel migration in the LJR amid the time of 1983– 2013 were evaluated by figuring lateral erosion, lateral deposition and trend of the shifting direction of the channel. Results showed that the sinuosity reduced from 2.09 to 1.9 and river length decreased from 125.32 km to 113.31 km in the previous 30 years, which progressively changed LJR to a straighter channel.

Darwish *et al*. (2016) documented the morphological changes beside the Nile Delta coast from 1945 to 2016. Landsat satellite imagery such as Landsat MSS, TM, ETM, ETM+ and OLI OF 1972, 1973, 1984, 2000, 2001, 2014, and 2015 was used in this study. In preprocessing the imagery was geometrically transformed to Universal Transverse Mercator projection. The resultant NDWI images highlight water bodies present in the study area. The Digital Shoreline Analysis System (DSAS) v.4.3, ArcGIS tool was used to compute statistics of rate-of-change from multiple coastline positions. They observed that the coastline's geomorphology significantly altered amid this era, particularly at Damietta and Rosetta projections, that are exceptionally disintegrated after development of the Aswan High Dam.

Reza and Islam (2016) conducted the assessment of fluvial channel dynamics of Padma river using remote sensing techniques. The behaviour of major channel patterns of the river was analysed from 1977 to 2000. Satellite imagery of

Landsat MSS (1977) and TM (1989) and ETM+ (2000) bands of 3 different years were used in this study. Three satellite images were mosaiced and geo-referenced to topographic sheet and base map (scale 1:50,000) and projected using the UTM (Universal Transverse Mercator)-46 N projection. Sinuosity ratio, braided index and island percentage of the study area were estimated for the year of 1977, 1989 and 2000 respectively. Results showed that the overall width of the Padma River has increased from around 4 km to 6 km during the last 23 years.

Materials and methods

CHAPTER III

MATERIALS AND METHODS

This chapter covers the study area, methods to analyse the changes in the river morphology, different softwares used and the methodology adopted to achieve the objectives of the study.

3.1 DESCRIPTION OF THE STUDY AREA

The Bharathapuzha ("River of Bhārata") is also known as the River Nila, Perar or Ponnanipuzha. It is the second longest river in Kerala with a total length of 209 km and it lies in the central part of Kerala state, India. The river is considered to be one of the west-flowing 'medium' rivers of the country and lies approximately between 10° 26' and 11° 13' north latitudes and 75° 53' and 77° 13' east longitudes. Bharathapuzha originates at Kovittola Betta of Kundra reserve forest in the Western Ghats, located in Tamil Nadu, at an elevation of 2336 m above MSL, and flows westward to join the Arabian Sea at Ponnani (10° 47' 13" N, 75° 54' 40" E) Kerala, India. Fig. 3.1 below shows the location map of Bharathapuzha watershed. The river follows northwards till Pollachi from the head waters at Anamalai hills and then takes a westward course. The confluence of Chitturpuzha and Kalpathipuzha at Parli creates Bharathapuzha which flow westwards. Bharathapuzha's conflux with Gayathripuzha, originating from the Anaimalai hills, is at Mayannur. The Thuthapuzha joins Bharathapuzha at Pallipuram in its westward flow towards the Arabian Sea. The four major tributaries of the river are Kalpathipuzha, Gayathripuzha, Thootha, and Chitturpuzha. The river has a total basin area of 6,186 km^2 of which 4,400 km^2 falls in the state of Kerala occupying about one-ninth of its total geographical area and the rest in Tamil Nadu. Out of the total basin area in Kerala, about 87 per cent falls within Palakkad district, 12 per cent in Malappuram district and the remaining 1 per cent in Thrissur district (CWRDM, 1991, 2004). The flow regime of the river covers highlands (> 76 m), midlands (76-8 m) and low lands (< 8 m). The surface water potential of the basin is 7478 million m^3 and the total utilizable yield is 4,146 million m^3. The average discharge of the river at its mouth is 161 m^3/s. Fig. 3.2 represents the Bharathapuzha watershed.

The river valley is considered as the cradle of civilisation in Kerala and Nila has groomed the culture and life of south Malabar part of Kerala. The river is the life line water resource for almost one-eighth of Kerala's population residing in four administrative divisions, namely Malappuram, Thrissur and Palakkad districts of Kerala and partly Coimbatore, and Thiruppur districts of Tamil Nadu. Eleven irrigation projects and several surface dams in the river basin cater 493064 hectare agriculture. The general land use in the bowl fluctuates as indicated by the nearby physiography. Rice and coconut are the predominant yields in the beach front areas of the bowl. In the mid grounds, the real yields are rice, banana, custard, occasional vegetables and coconut while in the high land region and some of the mid land region rubber plantations and coconut grooves dominates.

The climate of the basin is humid tropical (Guhathakurta and Rajeevan, 2007). The river basin experiences more or less a unique climate realm from the rest of the state of Kerala perhaps for its location, beginning in the eastern aspect of the Palakkad plains, in the Palakkad Gap, flanked by mountain ranges of the Western Ghats. Average annual discharge of the river is around 3.94 km^3 (Raj and Azeez, 2009) and the geology of the area is characterized by archaean crystalline formation (gneiss, schist, charnockite), tertiary formations, sub recent laterite and recent riverine alluvium. Major drainage pattern of the area is dendritic in nature and is highly influenced by the topography. Most of the area experiences high humidity during the monsoon months from June to October.

The Bharathapuzha river was once fascinated by writers, dancers and musicians and was lively hood to agriculturists and labourers. But now it became a dead river with huge dry stretches. Noticeably, among the grave causes for the degradation of the river, sand mining is reported to be the dominant one.

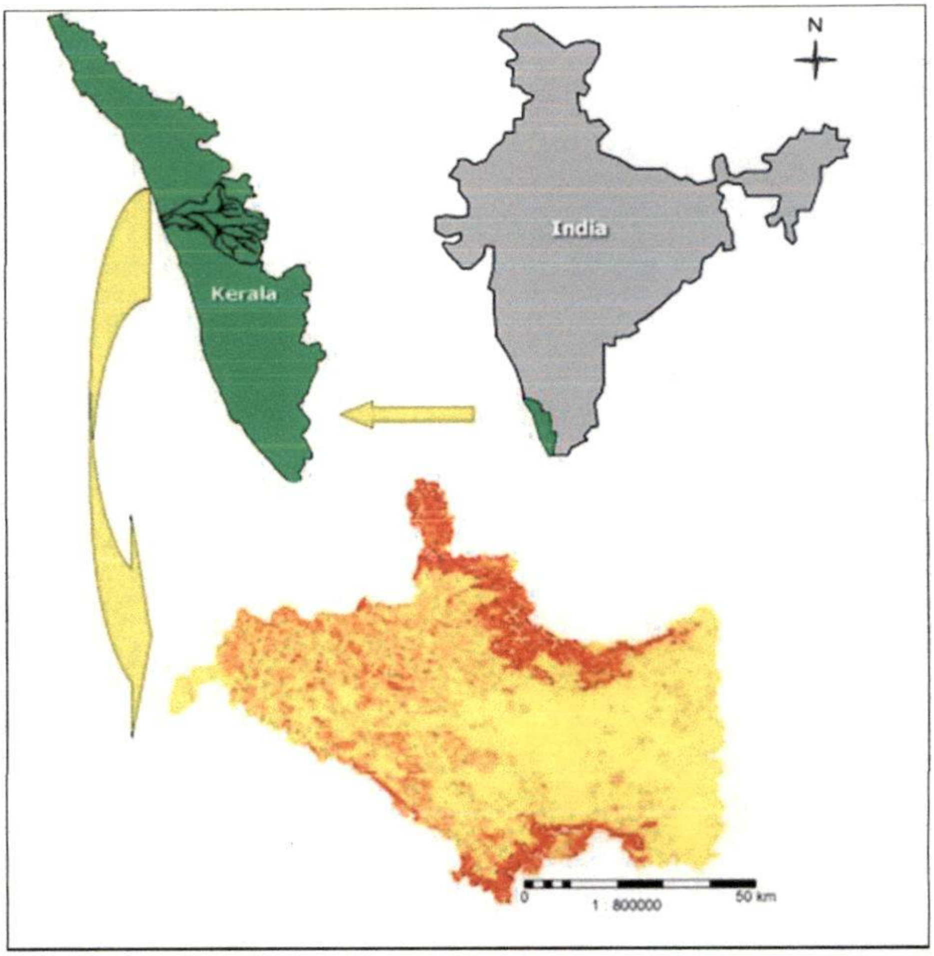

Fig. 3.1 Location map of Bharathapuzha watershed

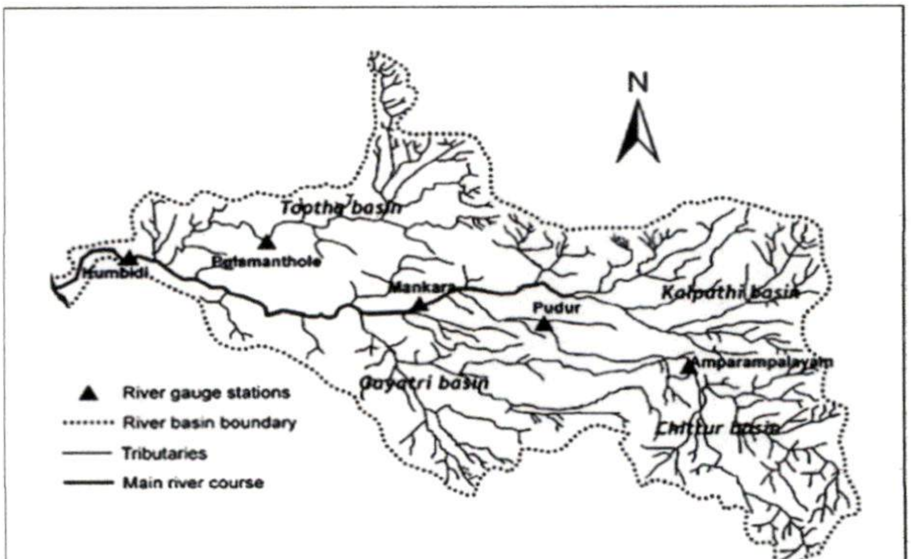

Fig. 3.2 Bharathapuzha watershed

Other activities like dynamiting of rocks, brick-making, lime-stone quarrying and pollutants from agricultural sources besides dumping of municipal wastes have also contributed to the destruction of the river. The main culprits are the 18 stations (kadavus) in Ottappalam which are licensed to carry out sand quarrying and the numerous private kadavus owned by influential persons. Even small-scale quarrying contributes to extensive damage of the river. The mining activity is particularly bad in the stretch between Pattambi and Kuttippuram, as the steepness decreases in this reach. The removal of sand has put an end to the percolation of water from the river bed to recharge the ground water in the area. It has also resulted in an acute water scarcity in the basin, particularly during the summer months. The extensive removal of sand has resulted in the exposure of rocks and the entire river bed is now overgrown with wild grass. The breeding pattern of aquatic organisms has been disturbed and even benthic organisms have been affected. Due to the decrease in wetted perimeter and increase in hydraulic gradient, the velocity of the water flow increases, making it violent during monsoons. The lean flow in the river also causes saline water back flow into the river channel.

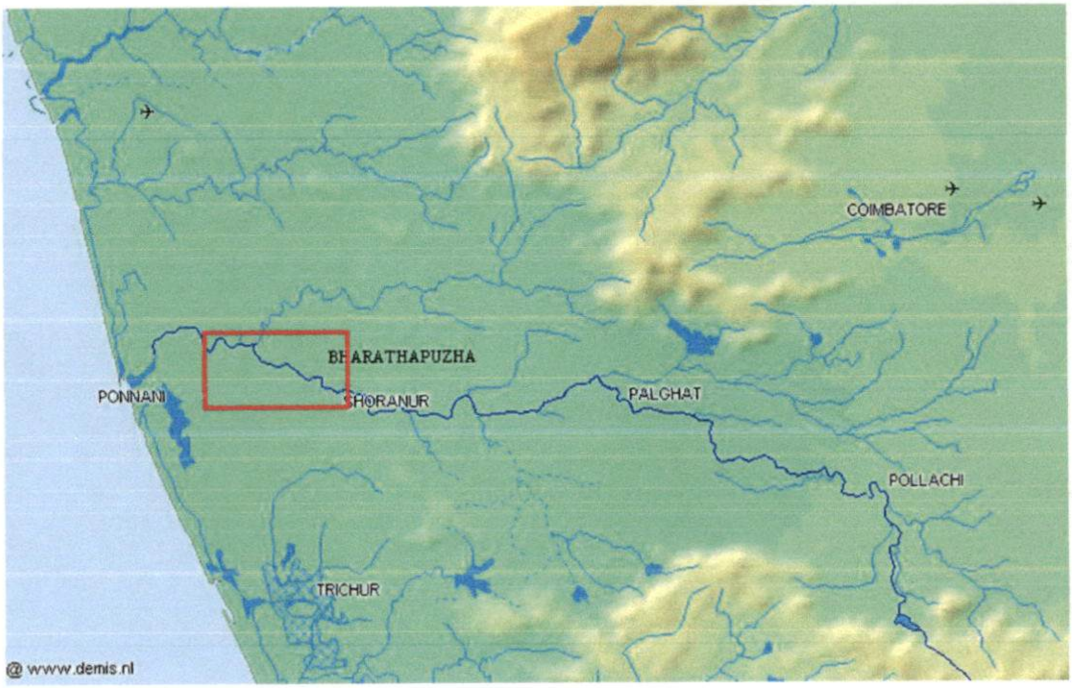

Fig. 3.3 Location map of Kuttippuram to Pattambi reach

In short, the entire river system is being destroyed and life forms dependent on it are under threat. Nowadays the present state of the is seriously considered by the people, authorities, scientist, environmentalist and other stake holders. Considering all the above facts the river reach lying in between the towns Kuttippuram (10°50′38″N, 76°01′58″E) in Malappuram district and Pattambi (10° 45′ 21.72″ N, 76° 34′ 23.18″ E) in Palakkad district had been selected as the study area. Fig. 3.3, 3.4 and 3.5 shows the map of study area.

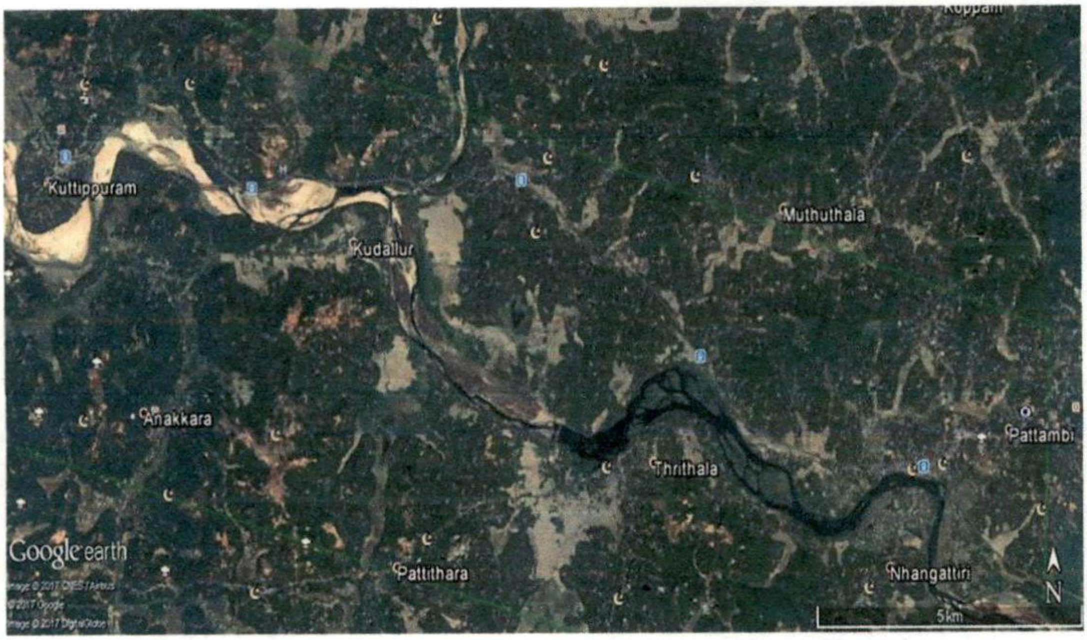

Fig. 3.4 Google earth image of Kuttippuram to Pattambi reach

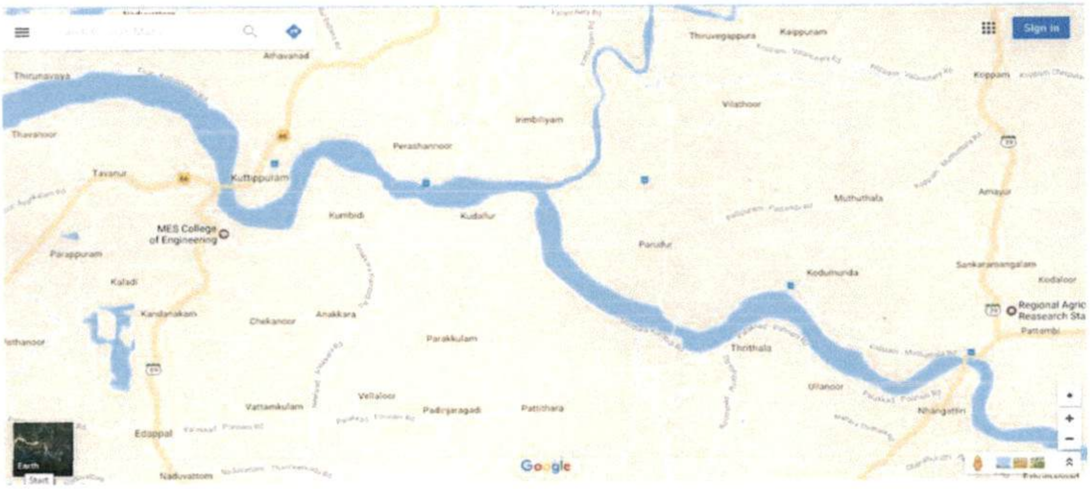

Fig. 3.5 Google map image of Kuttippuram to Pattambi reach

3.2 DATA COLLECTION

DEM imageries were used to evaluate the effect of sand mining on the morphology of the Bharathapuzha river and its adjoining banks in the severely affected reach between Kuttippuram and Pattambi by analyzing the cross-sectional details. CARTOSAT-1 DEM and SRTM DEM of the study area for the time periods 2014 and 2000 acquired from Earth Explorer and Bhuvan respectively were used to analyze the cross-sectional details. Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) imageries of the time periods 1990 and 2017 respectively were used to analyze the spatial and temporal variations in the river reach considered. All imageries are of 30 m resolution. The imageries were processed and assessed using ArcGIS 10.5 software.

3.2.1 Earth Explorer

Earth Explorer provides online search, display browsing, metadata export, and data download of earth science data from the archives of the USGS. Earth Explorer provides an enhanced user interface using state-of-the art JavaScript libraries, Hypertext Preprocessor (PHP), and the advanced Oracle spatial engine.

A. Key features in Earth Explorer include:

- Fast, geospatial search engine
- Map viewer for viewing overlay footprints and browse overlays
- Simple, fast Graphical User Interface (GUI)
- Data access tool to search and discover data
- Textual query capability
- Keyhole Markup Language (KML) export capability to interface with Google Earth
- Save or export queries, results, and map overlay for reuse
- Request on-demand products
- Access to browse images from standard products
- User authentication service for access to specialized datasets and tools
- Access to Landsat Data Continuity Mission (LDCM) quality band data

- Standard product downloads
- User notifications of new acquisitions and available products through subscription services
- Updated software code base supporting JavaScript and PHP

The Earth Explorer user interface (Fig. 3.6) provides the overall capability for users to interact with the Earth Explorer components and services. The body of Earth Explorer is composed of the Data Search Functions and the Google Map components. The Data Search components are parted among four tabs and allow users to enter search criteria, advanced search, select datasets to query, and examine results in a tabular window. Google Map is a useful tool for determining a search area and for verifying whether that results fall in the area of interest. All of Earth Explorer's features, including saving search criteria, downloading data, and accessing subscription services can be used by registered users, as the USGS Earth Explorer system requires users/customers to register to download the data.

The majority of the datasets are available for download from the USGS at no cost. A few datasets have a minimal fee to cover the cost of increasing the priority in production. Each criteria page is different and is based on the unique dataset attributes defined for that dataset. The specific search criteria include:

- WRS Path
- WRS Row
- Cloud Cover
- Data Category
- Day Night
- Landsat Scene Identifier

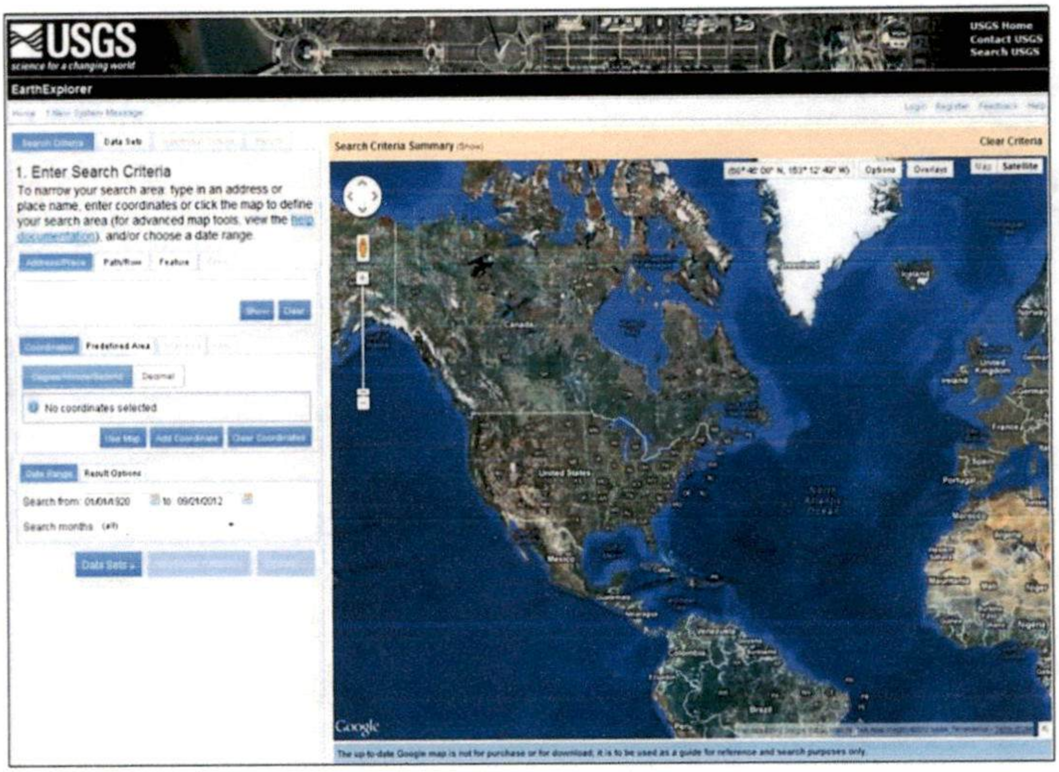

Fig. 3.6 Earth Explorer user interface

3.2.2 Bhuvan

Bhuvan is a Geoportal of Indian Space Research Organization (ISRO), hosted through URL http://bhuvan.nrsc.gov.in. with a host of wide ranging services that cover visualization of multi-date, multi-platform, multi-sensor satellite data, thematic map display, query and analysis, free data downloads and products, near real-time disaster services, apps for crowd sourcing and diverse geospatial applications. Bhuvan is the only government platform in India that is operational in public domain with PAN-India coverage of systematic geographical database. Fig. 3.7 shows the Bhuvan user interface. The platform allows seamless transitions from national to village level depiction of variety of geospatial datasets that are unique to Bhuvan. The platform not only enables good base data and image display up to 1m spatial resolution, but also provides hydrological base for the country from basin to watershed, transport network from national highways to city roads and rich location information. Apart from this, the scientifically derived Digital Surface

Model for entire country is another unique feature by Bhuvan that gives excellent depiction of the country's topography on the fly.

Bhuvan, as a platform, is open and being used by diverse user community. The Government agencies use this platform to share and host their data, as per their requirements, enabling specific applications of their choice. Bhuvan is used as a data and product clearing house for supporting scientific and Remote Sensing based projects. The data and products can be downloaded from NRSC/ISRO Open data and product archive. Requirement of users to carry out remote sensing based projects specially by universities, researchers and departments is fulfilled by providing free satellite data and products through NRSC Open Data Archives. Fig. 3.8 shows the data selection pane. With all these capabilities, today Bhuvan is reckoned as one of the most unique GIS platform of the country that is freely accessible on the internet used by wide varieties of user community including school children.

Fig. 3.7 Bhuvan user interface

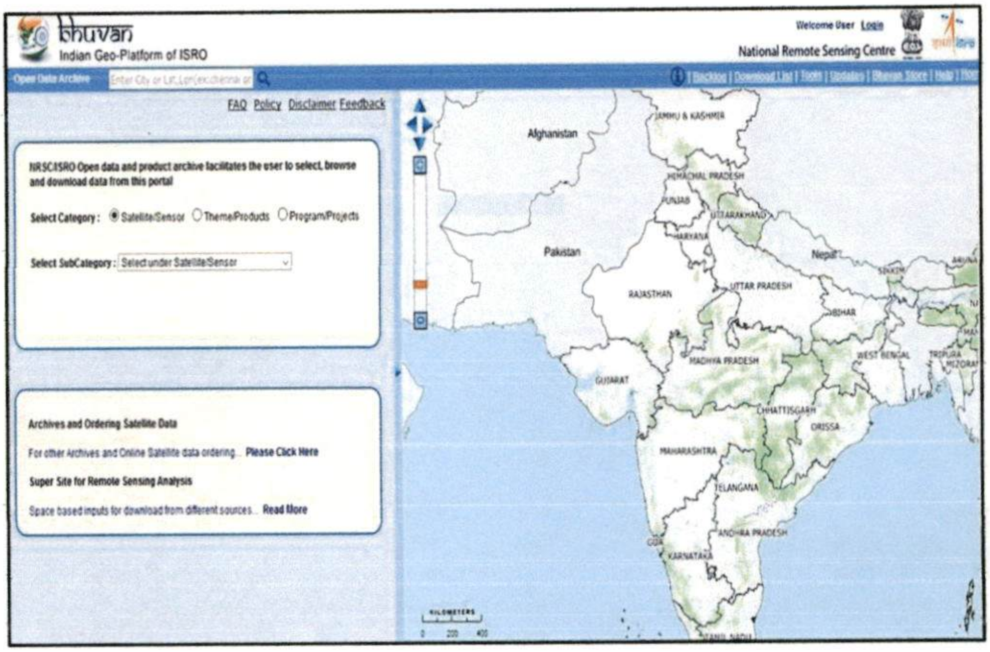

Fig. 3.8 Data selection pane of Bhuvan

3.2.3 Comparison of Field Data and DEM Data

Total station survey at seven Kadavus which were accessible, were conducted to analyse the accuracy of the profile graph obtained using Elevation Profile add-in. Kadavus are places in the river reach were sand mining is a usual practice. Kadavus for survey were selected based on the areas with highest rate of mining. According to that the seven Kadavus selected were Vellanchery Kadavu, Nilayoram park, Mallur Kadvu, Kattadi Kadavu, Keltron Kadavu, Ummathur Ambala Kadavu and Kumbidi Ner Kadavu. Table 3.1 and Fig. 3.9 shows the location details of the seven Kadavus. Plates. 3.1 and 3.2 represents the Mallur Kadavu and Vellanchery Kadavu. Total station survey was conducted in three sections at 30 m interval in each Kadavu. A total of 21 sections were surveyed. Data was collected from the accessible points only which forms only a representative portion in the actual cross section. According to the data obtained from the field a cross section profile graph for the seven Kadavus were drawn. Similarly, cross-section lines representing these sections at each Kadavu were drawn in the latest DEM available from Bhuvan and cross profiles were generated. The cross-section profile graphs from field were compared with the profile obtained from Elevation profile add-in and the percentage error was calculated to find out the accuracy of DEM for cross section analysis.

Table 3. 1 Location of kadavus selected for total station survey

Name of Kadavu	**Latitude**	**Longitude**
Vellanchery	10^{0} 51’ 27.2” N	76^{0} 00’ 41.7” E
Mallur	10^{0} 50’ 24.8” N	76^{0} 01’ 20.0” E
Nila park	10^{0} 50’ 50.8” N	76^{0} 01’ 32.0” E
Keltron	10^{0} 49’ 56.0” N	76^{0} 01’ 34.1” E
Kattadi	10^{0} 49’ 51.4” N	76^{0} 02’ 12.1” E
Kumbidi Ner Kadavu	10^{0} 50’ 18.2” N	76^{0} 02’ 22.5” E
Ummathur Ambalam	10^{0} 50’ 30.9” N	76^{0} 03’ 21.4” E

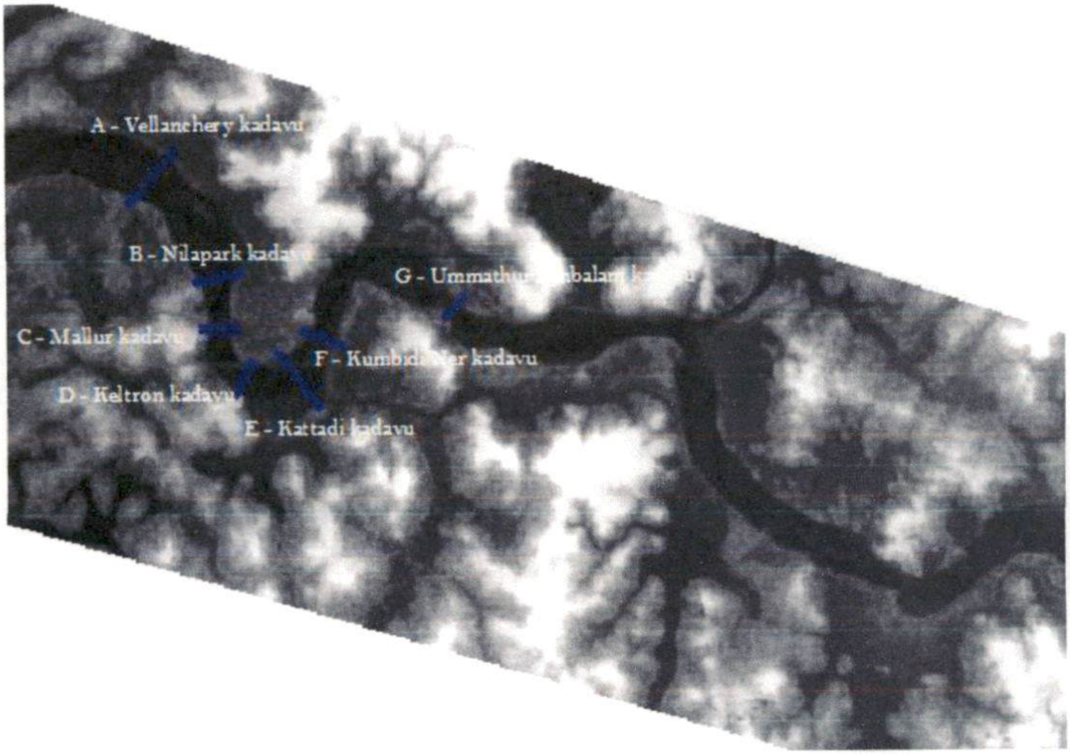

Fig. 3.9 Kadavus selected for total station survey

Plate 3.1 Mallur Kadavu

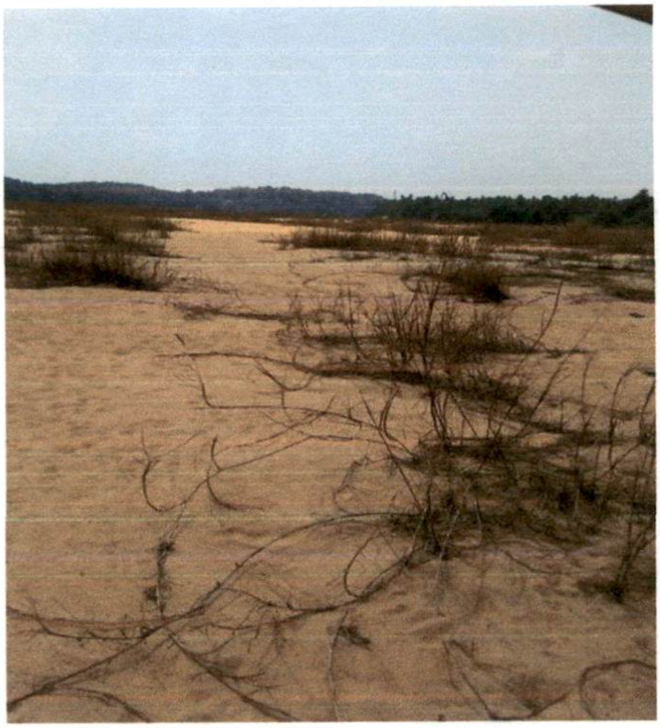

Plate 3.2 Vellanchery Kadavu

3.3 IMAGE DATA PROCESSING

Image processing and assessment of the impact of sand mining on the morphology of the severely affected reach of Bharathapuzha river were carried out using the ArcGIS 10.5 software.

3.3.1 ArcGIS 10.5 Software

ArcGIS is a geographic information system (GIS) for working with maps and geographic information. It performs the function of creating maps, compiles geographic data, analyze mapped information, share and discover geographic information, using maps and geographic information in a range of applications, and manage geographic information in a database. An infrastructure is provided by the system to create maps and geographic information is made available throughout an organization, across a community, and openly on the Web. Contextual tools for mapping and spatial reasoning is also provided by ArcGIS to explore data and share location-based insights. ArcGIS in the field of imagery and remote sensing gives everything needed to manage, process, analyze, and share imagery. ArcGIS includes the following Windows desktop software:

- ArcReader, which allows one to view and query maps created with the other ArcGIS products;
- ArcGIS for Desktop, which is licensed under three functionality levels:
    - ArcGIS for Desktop Basic (formerly known as ArcView), which allows one to view spatial data, create layered maps, and perform basic spatial analysis;
    - ArcGIS for Desktop Standard (formerly known as ArcEditor), which in addition to the functionality of ArcView, includes more advanced tools for manipulation of shapefiles and geodatabases;
    - ArcGIS for Desktop Advanced (formerly known as ArcInfo), which includes capabilities for data manipulation, editing, and analysis.

ArcGIS 10.5, a major release that comes with many new capabilities with regards to its server and cloud capabilities. The big takeaways for 10.5 are large-scale analytics, big data capabilities plus a renamed and reorganized ArcGIS Server product family. ArcGIS Server has been renamed ArcGIS Enterprise as of the 10.5 release. As it turns out, ArcGIS Enterprise is now a collective term for the ArcGIS for Server product family that includes ArcGIS Server, Portal for ArcGIS, ArcGIS Data Store, and ArcGIS Web Adaptor. Two of these individual products have been updated with new features as well: Portal for ArcGIS software component now has with 3D capabilities, while the ArcGIS Server software component enables you to set up five different servers with one single server software component. In addition to this, three other server-based products offer large-scale analytics and big data capabilities. It is worth noting is that these applications add more scalability with regards to spatial analytics to the platform.

The first ArcGIS Enterprise product adding large-scale analytics is ArcGIS GeoAnalytics Server, through tools that improve processing time for large volumes and detailed datasets. It is designed for space-time analysis on massive vector and tabular data. Second, there´s the ArcGIS Image Server product which enables fast and efficient processing, analysis and sharing of massive collections of imagery and rasters. Both ArcGIS GeoAnalytics Server and ArcGIS Image Server introduce distributed and parallelized computing, speeding up analysis time. Third, there´s ArcGIS GeoEvent Server, which replaces the ArcGIS Server GeoEvent Extension available in previous releases. It is designed to handle high volume, high velocity real-time and streaming data, provides solutions through on-the-fly analysis and dynamic aggregation of large datasets, easing data visualization. 10.5 also introduces portal to portal collaboration as a way of sharing content between multiple web GIS implementations. It is now possible to connect multiple on-premises ArcGIS organizations and distribute a Web GIS across a network of portals. The benefit of establishing a distributed Web GIS is to organize, network, and share content across departments and geographic areas.

ArcGIS Enterprise is known as the flexible server software for mapping and analytics that allows to easily manage the location enabled data and brings a browser-based GIS into the infrastructure. Designed for flexibility, the heart of ArcGIS Enterprise is powerful server software with specific capabilities to serve, map, and analyze geographic information. Powerful, collaborative, and secure; ArcGIS Enterprise is termed as the epitome of modern GIS.

Overview of ArcGIS Software:

a. Software Modules: (i.) ArcMap – software used to display, analyze, and create GIS data (Fig. 3.10). (ii.) ArcToolbox – set of tools and functions used to convert data formats, manage map projections, perform analysis, modify data (Fig. 3.11). (iii.) ArcCatalog- tool for viewing and managing spatial data files (Fig. 3.12).
b. Extensions: (i.) The Extensions dialog allows to load and unload software capabilities, allowing to enhance working environment with additional

objects, scripts and customization. (ii.) We can use extensions provided by ESRI and can also create our own.

c. Data Files in ArcGIS

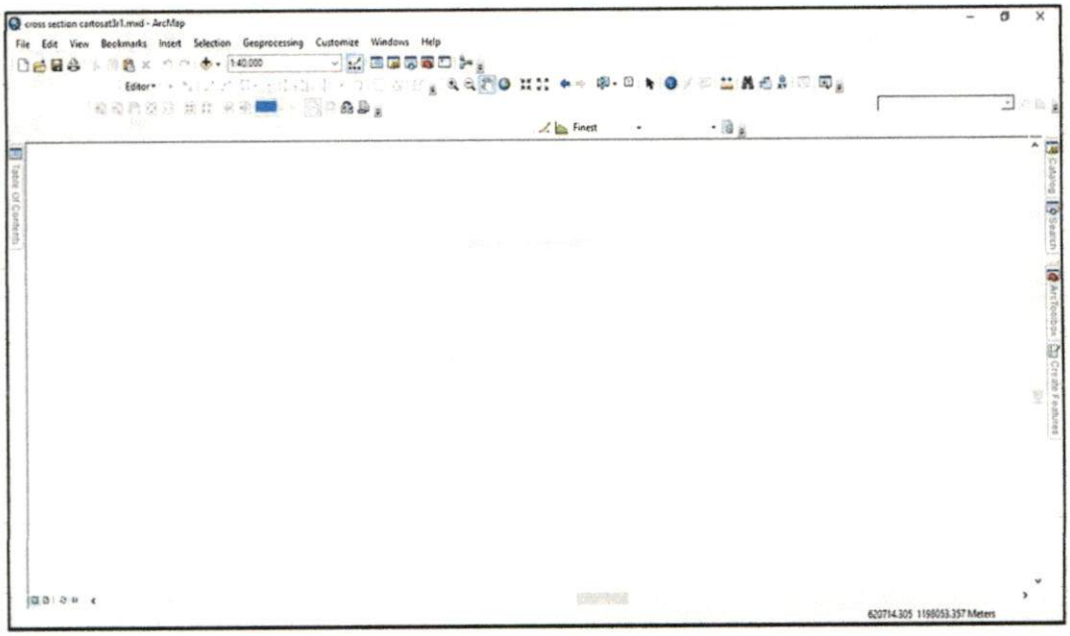

Fig. 3.10 ArcMap window

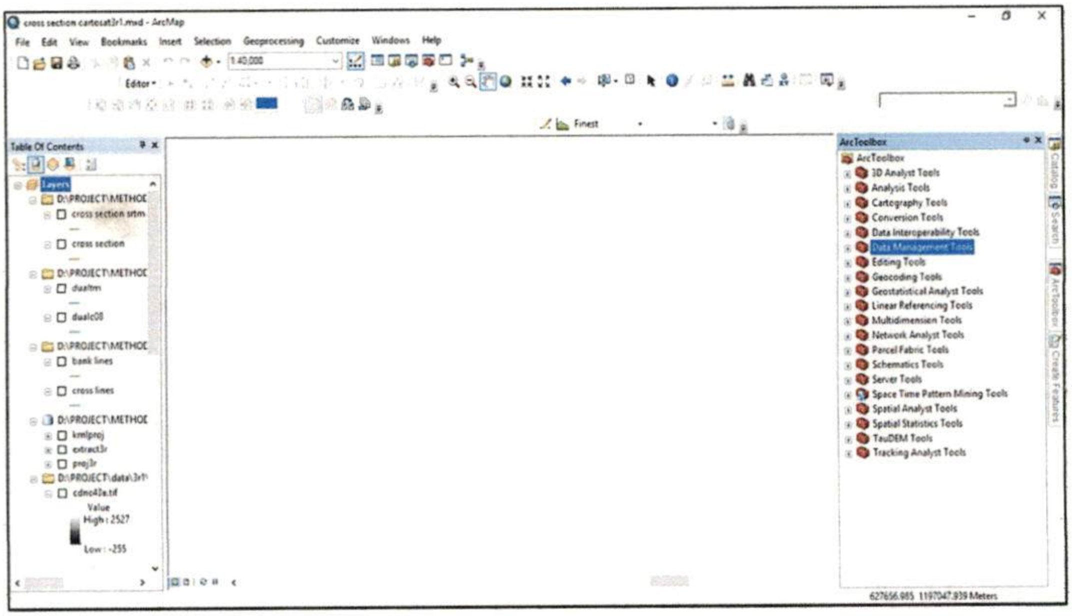

Fig. 3.11 ArcMap with Arc Toolbox

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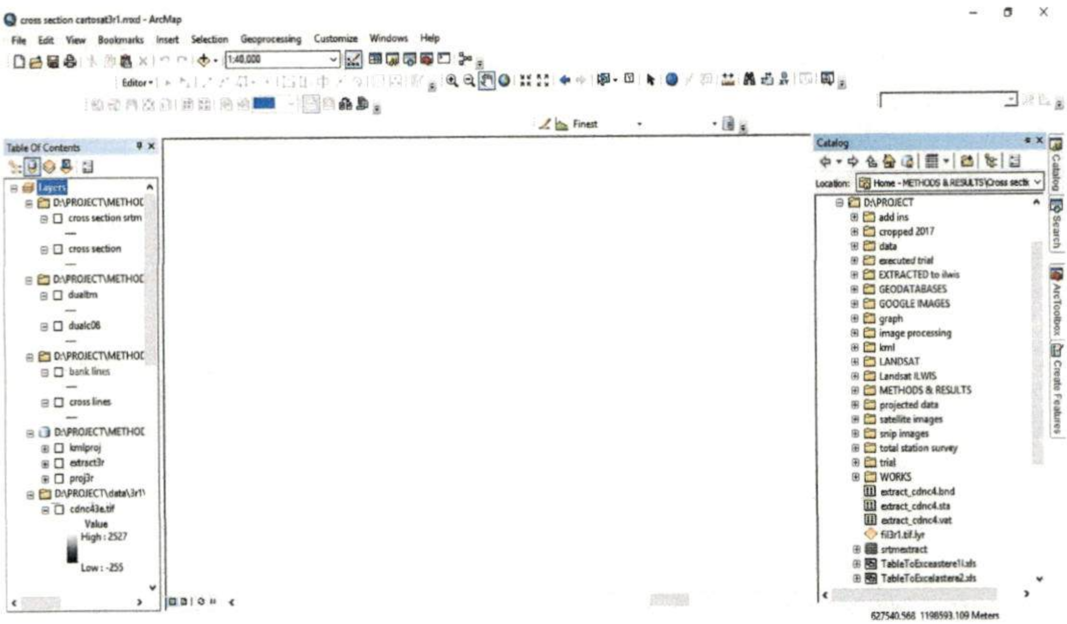

Fig. 3.12 ArcMap with Arc Catalog

The ArcGIS applications Arc Catalog, ArcMap, and Arc Toolbox offers a flexible environment to carry out the GIS work. ArcMap is a powerful mapping application which helps to view, edit, and analyze the geographic data. ArcMap program was launched by double clicking the ArcMap icon on the desktop. ArcMap along with Arc Catalog and Arc Toolbox were opened. A file geodatabase was created to store all the works done under this section. To have common projected coordinate system group layer properties were converted to WGS_1984_UTM ZONE 43N by editing the coordinate system tab under properties of group layer, as it's the coordinate system usually assigned to imageries in India. Imageries for the evaluation were added to the data frame by clicking the Add Data Button on the standard toolbar. All the added images were then mosaiced together to form a single image using the Mosaic tool in Data Management Tools of Arc Toolbox falling under the toolbox Raster -> Rater dataset (Fig. 3.13). Mosaiced image was projected to the coordinate system assigned to the group layer using the Project Raster tool. The study area was extracted from the imageries using the tool Extraction by Mask (Fig. 3.14), with reference to the feature mask data exported as a kml layer from google earth representing the study area (Fig. 3.15 and 3.16).

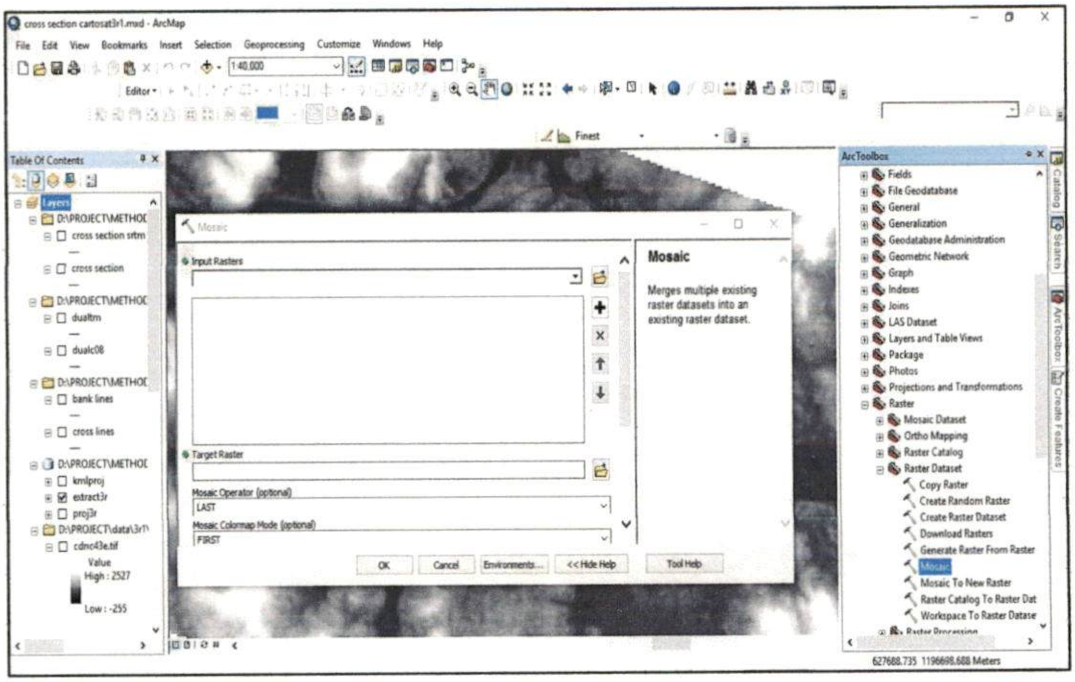

Fig. 3.13 Mosaicking of raster images

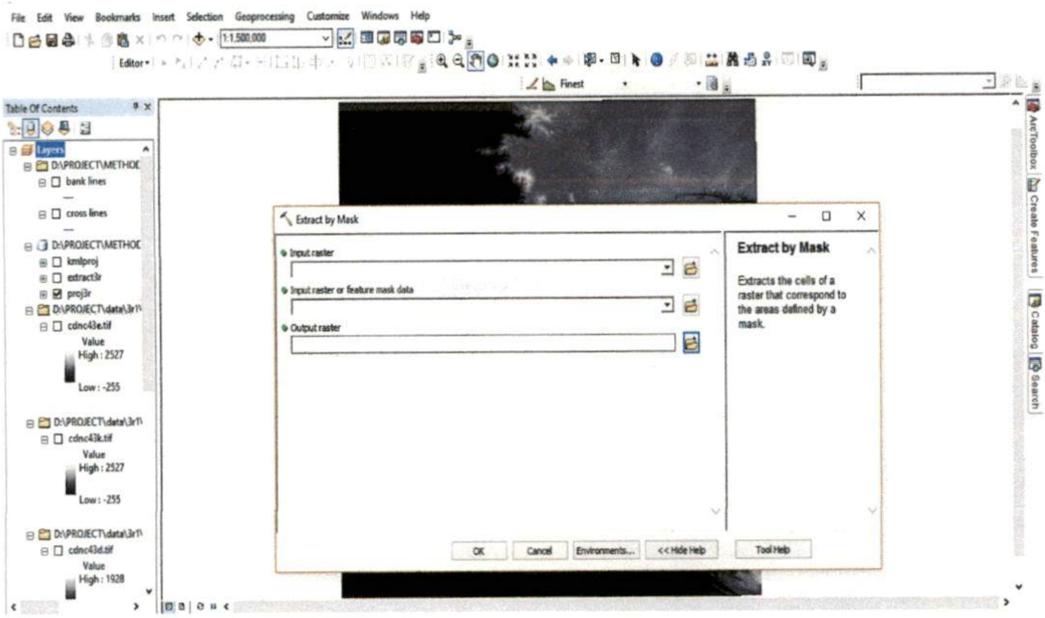

Fig. 3.14 Extraction by mask tool

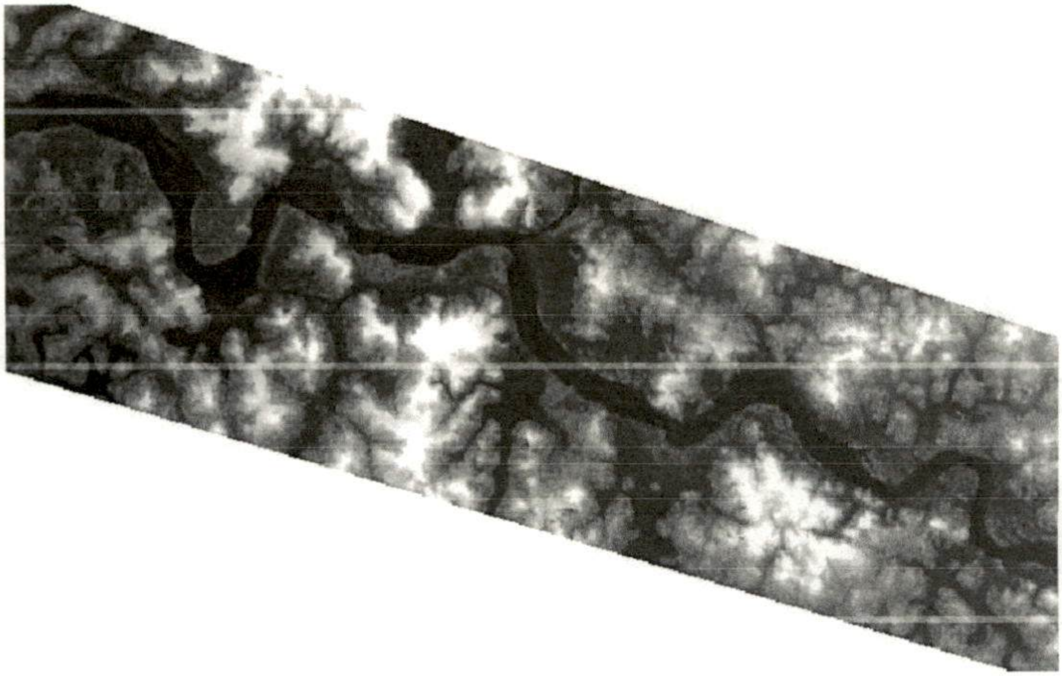

Fig. 3.15 Extracted study area from CARTOSAT DEM

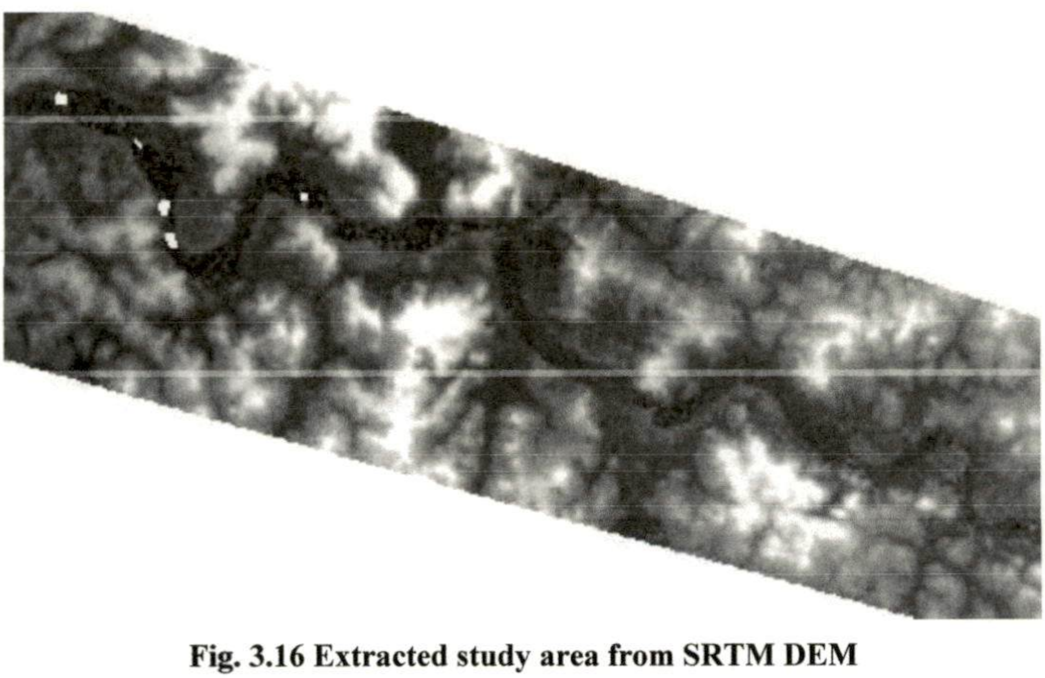

Fig. 3.16 Extracted study area from SRTM DEM

3.4 EVALUATION OF CHANNEL MORPHOLOGY AND ITS ADJOINING RIVER BANKS

To evaluate the morphological changes in the river channel, cross sectional profile of various sections of the river channel is found out using the add-in elevation profile. The Elevation Profile add-in toolbar (Fig. 3.17) allows to easily create profile graphs by simply drawing a line on the display in ArcGIS Desktop. It also allows to select existing line features and create profiles for them. By using this service, it is easy to create a profile graph on any elevation raster that is added to ArcMap. New shapefile of line feature was created by right clicking the folder in which the file is to be created and then selecting New-> Shapefile, to create profile graphs of channel cross section (Fig. 3.18). In the dialogue box that pop ups the name, feature class and the coordinate system for the new shapefile is entered (Fig. 3.19). 18 number of line features were drawn representing 18 cross sections (Fig. 3.20). Profile graphs of the river channel cross section was created using the Elevation Profile add-in. These same procedures were followed to process and analyze all the DEM imageries: CARTOSAT DEM, and SRTM. Results obtained by applying the Elevation Profile tool were compared to know the changes occurred to the channel cross sectional area between different time periods.

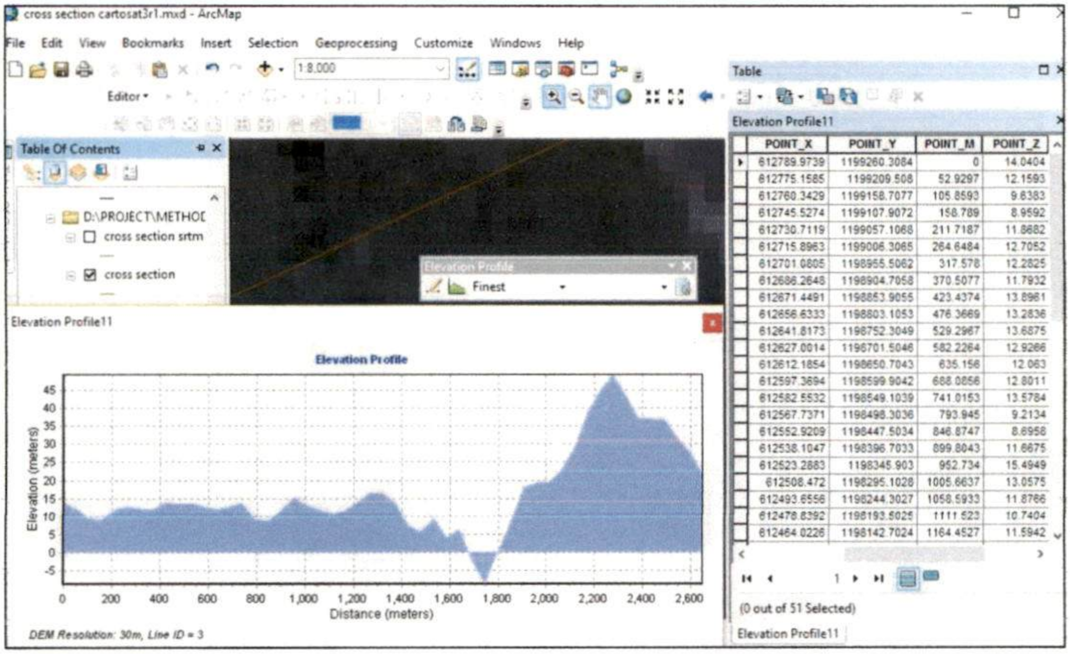

Fig. 3.17 Elevation Profile add-in

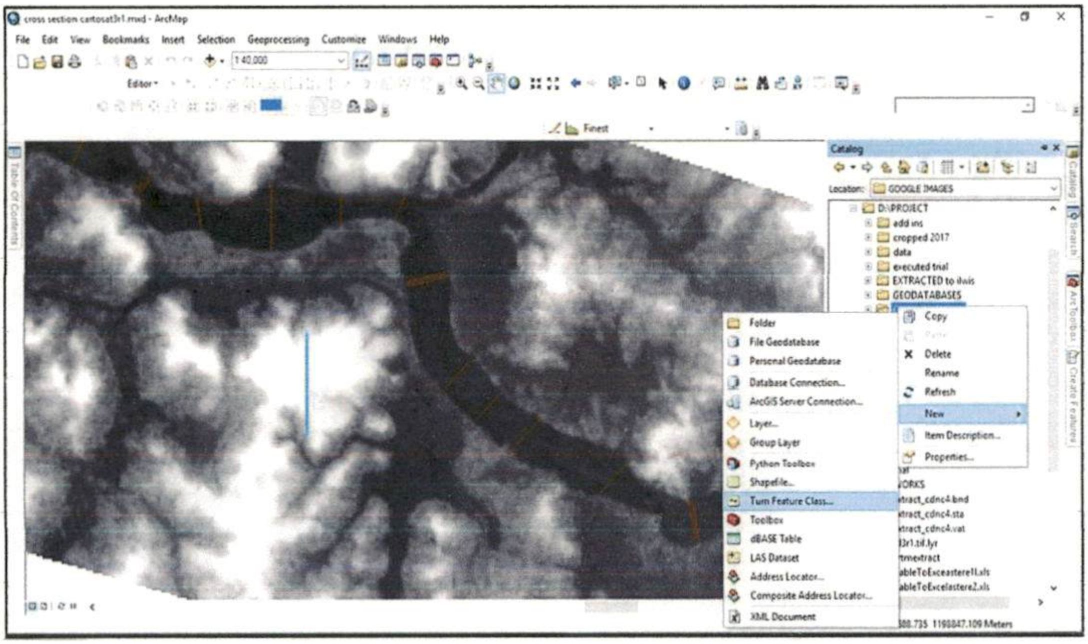

Fig. 3.18 Create a new shapefile

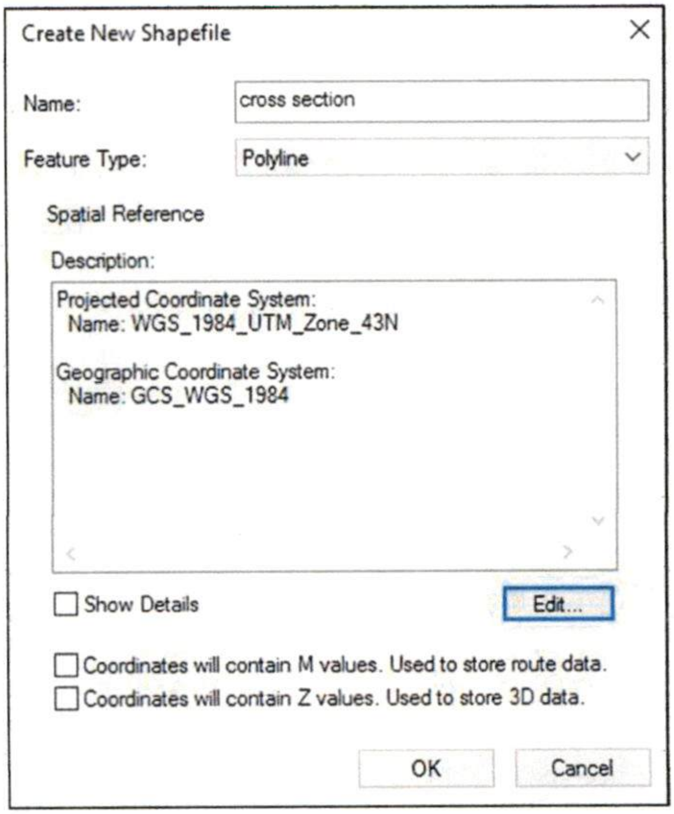

Fig. 3.19 Create new shapefile dialogue box

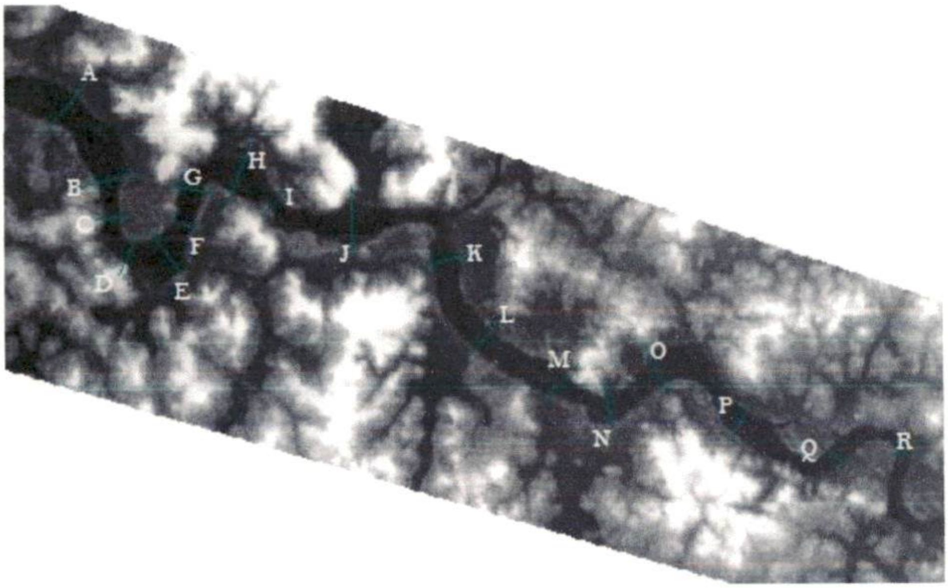

Fig. 3.20 Line feature to create profile graph of channel cross section

3.5 ANALYSIS OF THE SPATIAL AND TEMPORAL VARIATIONS OF CHANNEL ENLARGEMENT AND LATERAL MIGRATION

Landsat 4-5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) imageries of the time periods 1990 and 2017 respectively were used to analyze the spatial and temporal variations of channel enlargement and lateral migration in the reach considered. To analyze the spatial and temporal variation in the reach considered the study area was extracted by applying the method of Extraction by Mask, which was explained in the above section. To obtain the river reach details first the bank lines of the river was extracted by applying the NDWI index approach. The extracted bank lines were classified based on supervised classification and finally the river section was obtained by converting raster to polygon. The procedure is explained in detail in the following sections.

3.5.1 Bank line extraction

Although the classification, density slicing and NDWI approaches are all convenient and effective methods to delineate water areas, NDWI always produced the best results compared with the other approaches. The NDWI used in the study was developed by McFeeters (1996). NDWI denotes Normalized Difference Water Index, which is a remote sensing index to monitor the changes related to water content in water bodies.

The NDWI is expressed as follows:

$$NDWI = (Green - NIR) / (Green + NIR)$$

where Green and NIR represent the reflectance in the green and near infrared bands, respectively. The boundary of the water body was used as the bank line, and the water surface shown in the images was assumed to be the river channel. NDWI image was prepared by applying this equation to the Landsat images using Raster calculator tool in ArcGIS. Raster calculator was selected from Spatial analyst toolbox -> Map algebra -> Raster calculator. The green and near infrared bands in each of the Landsat images were found out based on the details obtained on the spectral bands from USGS earth explorer site and then according to the equation

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the bands were substituted in the raster calculator and the NDWI image was created for both Landsat TM and Landsat 8 OLI imageries. NDWI images for Landsat TM (Fig. 3.21) and Landsat OLI (**Fig.** 3.22) was created.

Fig. 3.21 NDWI image extracted from Landsat TM of 1990

Fig. 3.22 NDWI image extracted from Landsat OLI of 2017

River feature in the NDWI images were extracted as polygon feature to find out the shift in the river banks, channel migration rate, depositional and erosional area. River feature was extracted as polygon by the following steps:

1. Spatial analyst tool -> Multivariate -> Iso supervised classification (Fig. 3.23)
2. Spatial analyst tool -> Reclass -> Reclassify (Fig. 3.24)
3. Conversion tools -> From raster -> Raster to polygon (Fig. 3.25)

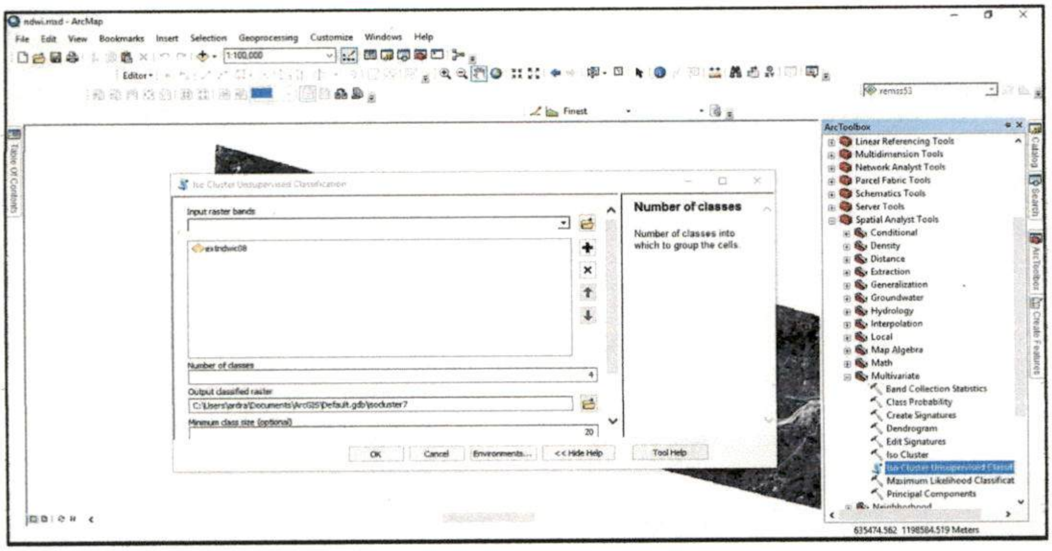

Fig. 3.23 Steps of Iso supervised classification

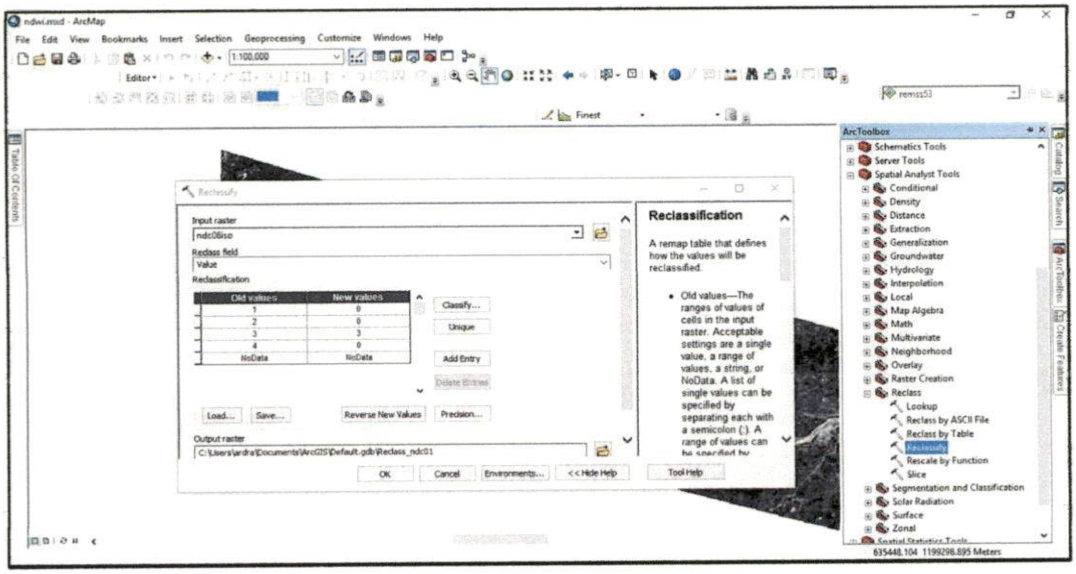

Fig. 3.24 Steps of reclassify

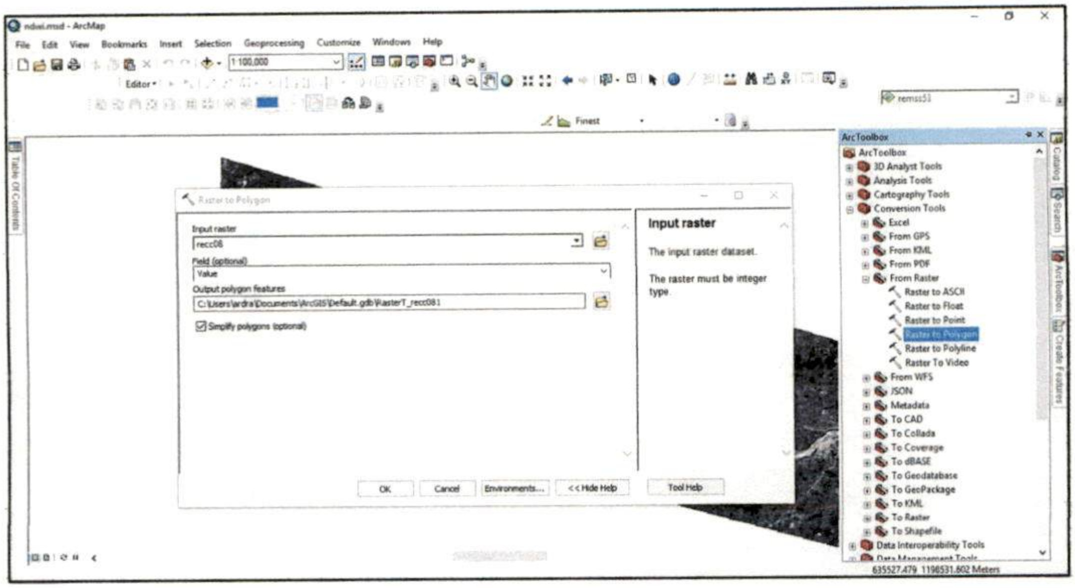

Fig. 3.25 Steps to convert raster to polygon

The whole raster image was converted to polygon feature (Fig. 3.26). The river feature was extracted from it by applying the edit option and copying the river feature to a new polygon feature layer (Fig. 3.27 and 3.28).

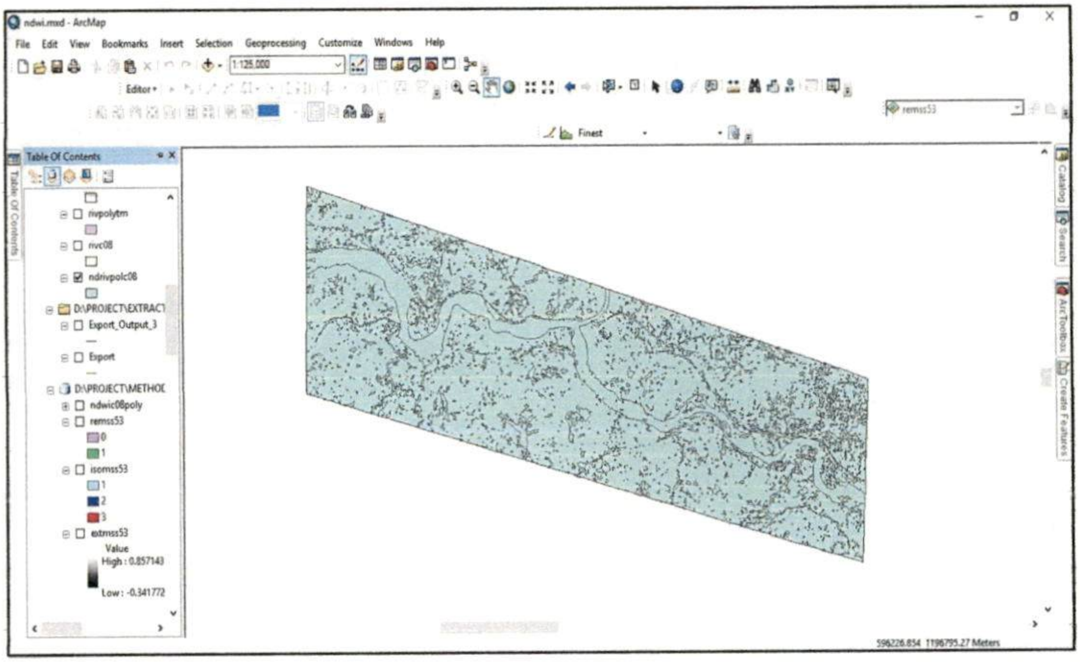

Fig. 3.26 Raster as polygon feature

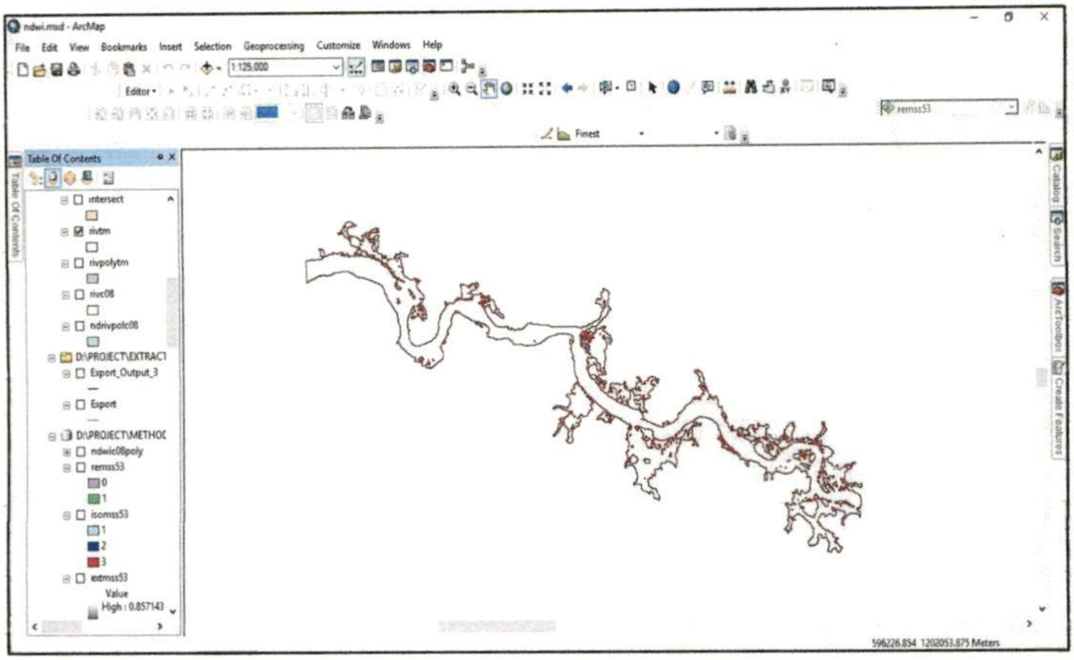

Fig. 3.27 River reach polygon from Landsat TM of 1990

River features obtained as polygon layer for the years 1990 and 2017 were overlaid to analyse the channel shift, migration rate and erosion and deposition areas (Fig. 3.29).

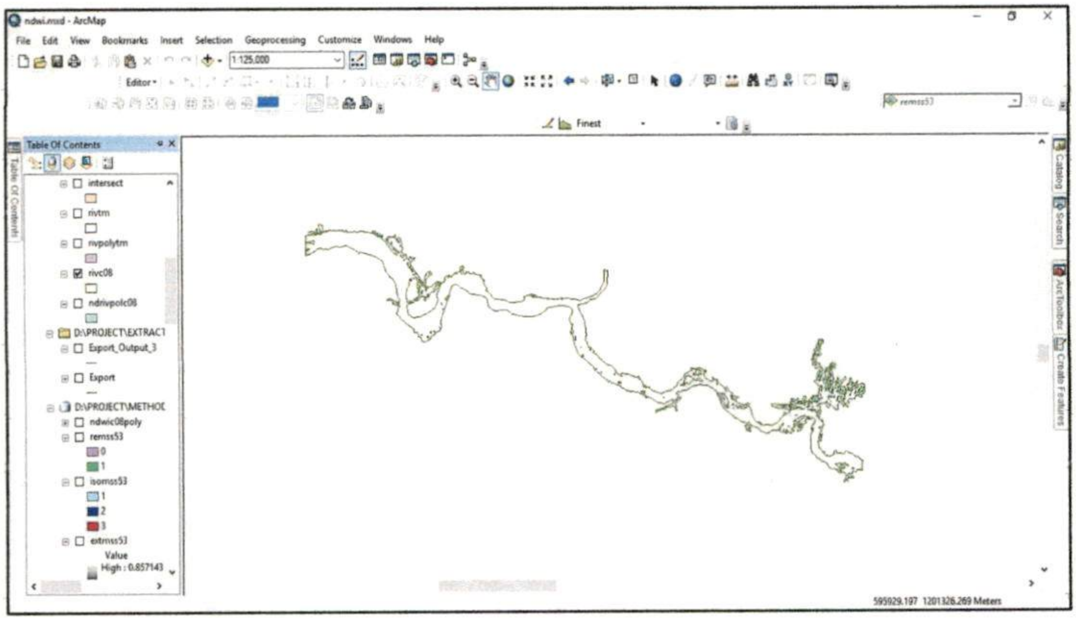

Fig. 3.28 River reach polygon from Landsat 8 OLI of 2017

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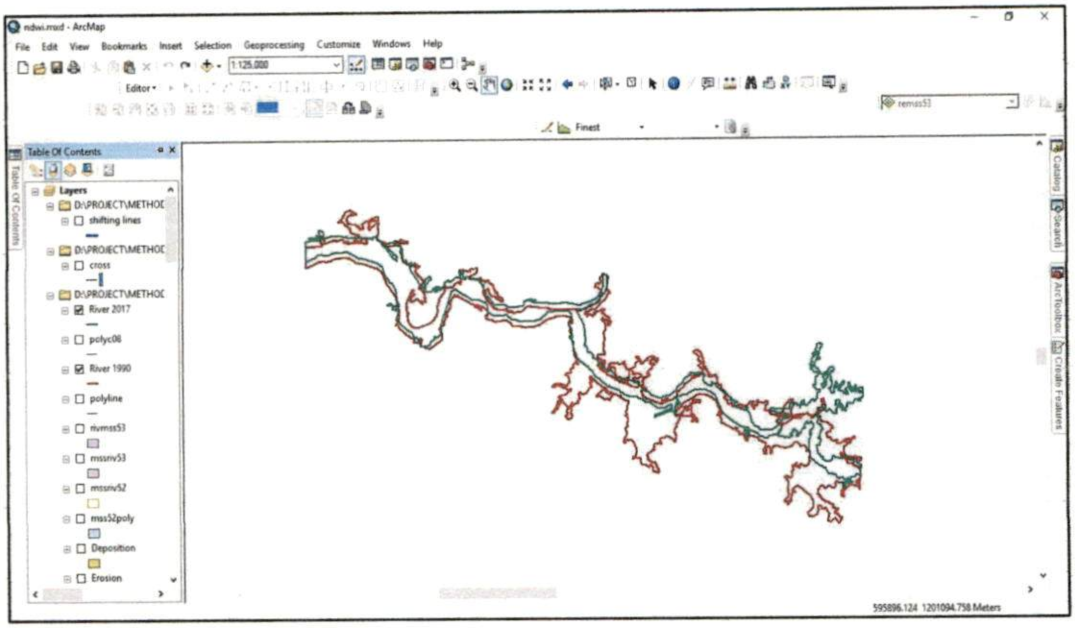

Fig. 3.29 Overlaid river polygon features

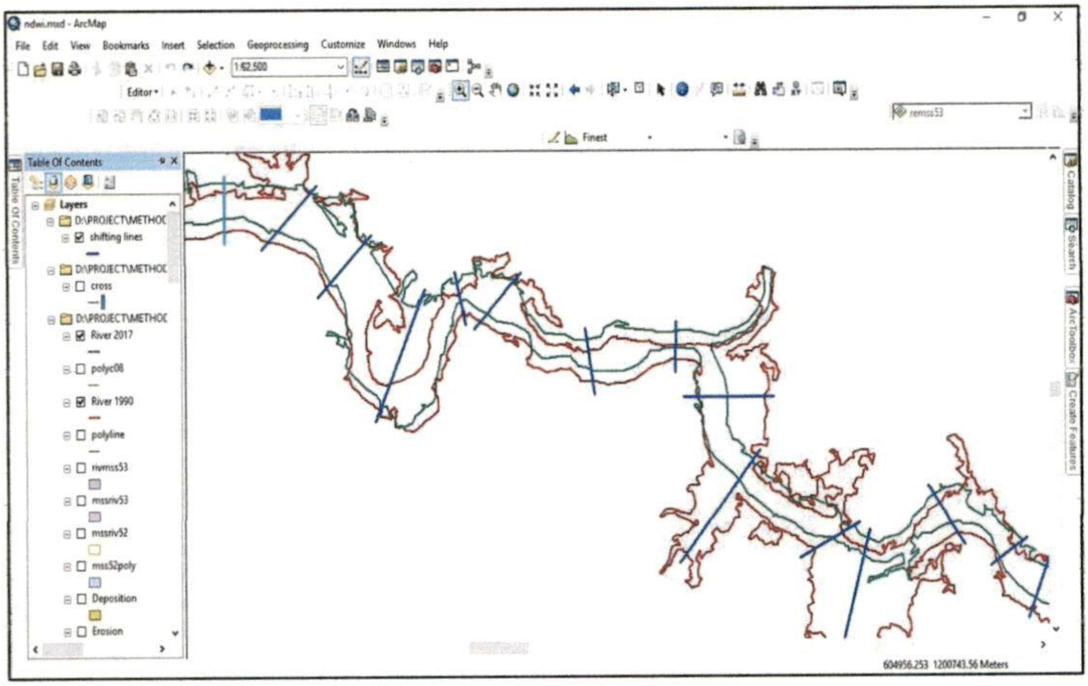

Fig. 3.30 Cross sections along which shift in banks were measured

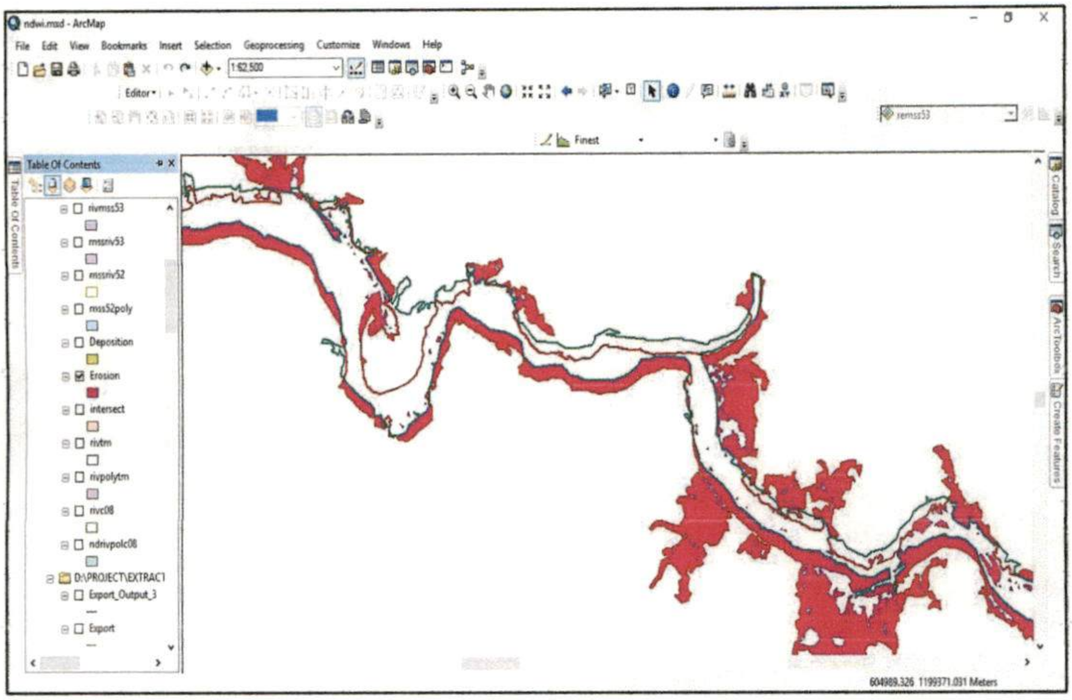

Fig. 3.31 Erosional area between 2017 and 1990

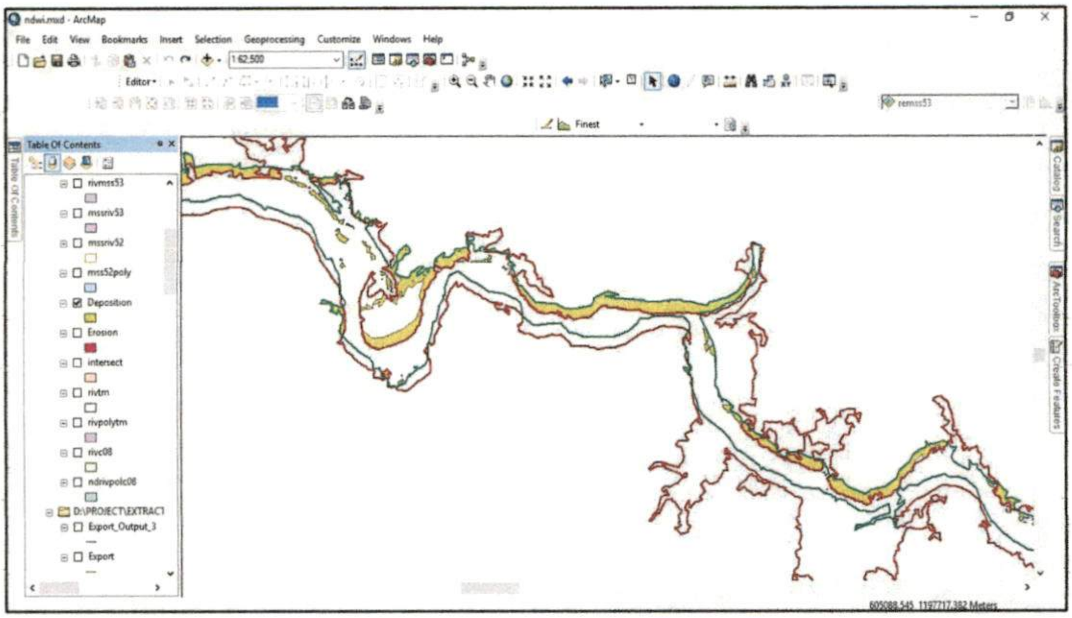

Fig. 3.32 Depositional area between 2017 and 1990

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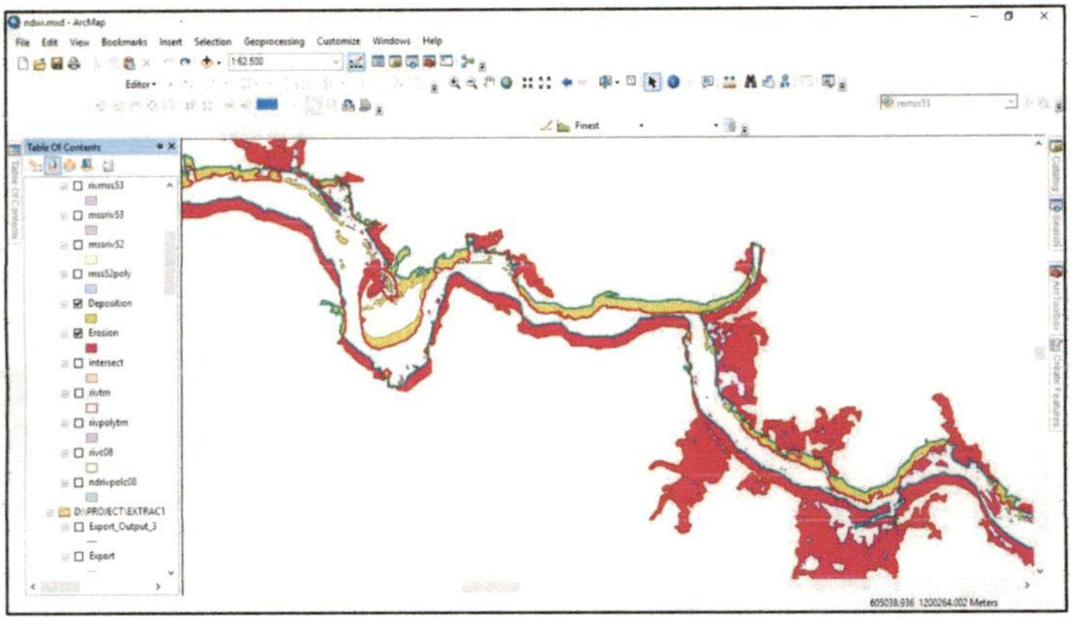

Fig. 3.33 Total erosional and depositional area in the reach during 2017 and 1990

Shift in each bank was measured along 18 cross sections drawn across the channels using measure tool (Fig. 3.30). Erosional and depositional area was found out by applying erase function on the overlaid polygon features. The lateral erosion and deposition area were defined as the area of a polygon enclosed by successive channel bank lines between the two-time intervals (Fig. 3.31 and 3.32). Analysing these images, the channel enlargement and lateral migration in the reach were found out. Fig. 3.33 represents the total depositional and erosional area in the reach.

Results and discussion

CHAPTER IV

RESULTS AND DISCUSSION

The temporal changes in the river channel and the adjoining river banks of Bharathapuzha river was assessed to determine the impacts of sand mining, using multitemporal multispectral remote sensing image assessment and GIS. DEM imageries of 2000 and 2014 were used for the evaluation of morphological changes in the river channel. LANDSAT imageries for the period 1990-2017 were used for the assessment of bank erosion, deposition and lateral migration. The GIS processing software used for this study was ArcGIS 10.5.

4.1 COMPARISON OF FIELD DATA AND DEM DATA

To know the accuracy of the elevation value obtained using Elevation profile add-in along each cross section, field value along seven cross sections was measured using total station survey technique. The cross section in the field was selected based on the convenience of measurement and based on the knowledge obtained by local people on the locations with severe sand mining. Survey was carried out only in the accessible portions of the Kadavus. The cross sections selected were Vellanchery Kadavu, Ummathur Kadavu, Mallur Kadavu, Kattadi Kadavu, Keltron Kadavu, Kumbidi Kadavu and Nila park. The accuracy of data is calculated based on the percentage error obtained by comparing the cross-sectional area found out using the field value and DEM value. Table 4.1 shows the percentage error obtained in each Kadavu in three sections classified as the cross section at Kadavu, upstream of Kadavu and downstream of Kadavu. The results showed that cross sectional area obtained from the DEM showed a percentage error varying from 0.41 per cent to 7.09 per cent with that from the field data. Average percentage error for elevations in the observed sections were 2.32 per cent. These results show that the elevation profile obtained from DEMs have sufficient accuracy for use in the analysis.

Table 4. 1. Percentage error calculation in the cross section

Cross sectional area of kadavus in each section (m^2)									
	At Kadavu		Percentage error	Upstream of Kadavu		Percentage error	Downstream of Kadavu		Percentage error
Kadvus	Field value	DEM value		Field value	DEM value		Field value	DEM value	
Vellanchery	9454.36	9523.66	0.73	9480.47	9702.17	2.29	9620.05	9698.88	0.81
Mallur Nila park	4482.98	4602.52	2.6	4145.61	4305.61	3.72	4522.22	4807.69	5.94
Bridge kadavu	3288.01	3401.04	3.32	3861.74	3877.63	0.41	3574.54	3652.54	2.14
Keltron	4321.87	4401.23	1.8	4966.47	5064.34	1.93	3559.01	3633.97	2.06
Kattadi	14371.34	14509.86	0.95	15453.69	15580.93	0.82	13610.53	13683.33	0.53
Nerkadavu	6130.69	6203.45	1.17	5752.96	5845.38	1.58	5532.96	5560.34	0.49
Ummathur ambalam	2478.16	2667.25	7.09	2909.44	2988.99	2.66	2460.43	2605.26	5.56

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4.2 ASSESSMENT OF MORPHOLOGICAL CHANGES

The impacts of sand mining on river channel and its adjoining river banks were assessed by analysing the changes in the 18-cross sections drawn across the river channel. River morphological changes indicates the change in shape and direction of river channel over time. Morphological changes of the river channel were analysed using the DEM imageries during 2000-2014. The spatial and temporal changes were analysed using LANDSAT images during 1990-2017. Each cross section is explained below.

4.2.1 Cross Section A

Section A located at 10^0 51' 27.2" N, 76^0 00' 41.7" E is known as Vellanchery Kadavu. This section also depicted a highly undulating cross section which describes the area with extreme rate of sand mining. The rate of downcutting was high than the rate of channel widening. The average change in depth was 1.03 m. The section observed an area change of 968.98 m^2 due to erosion. The main cause of such a large change in area was explained by the severity of sand mining in the section. This section was the wider section among all other sections. Field visit had depicted the drastic situation of the area with many depressions here and there in the channel section leaving the section unlevelled. The highest area change was also resulted in the same section. This section was considered as one of the mostly affected area due to illegal sand mining. Fig. 4.1 represents the change in depth along the section A.

4.2.2 Cross Section B

Section B is the Nila Park Kadavu in actual field. The location of section is given by 10^0 50' 50.8" N, 76^0 01' 32.0" E. The section was highly undulating and varying. This section was a major area of sand mining from many years. The channel experienced high rate of downcutting than channel widening. A small amount of sand deposition was seen in the middle of channel similar to a sand dune. The average change in depth was 0.95 m. The channel experienced an area change of 538.95 m^2 due to erosion or channel degradation. Sand mining was the main reason for such a drastic change. The highly undulated river bed denoted the extremity of sand mining in the area. Fig. 4.2 represents the change in depth along the section B.

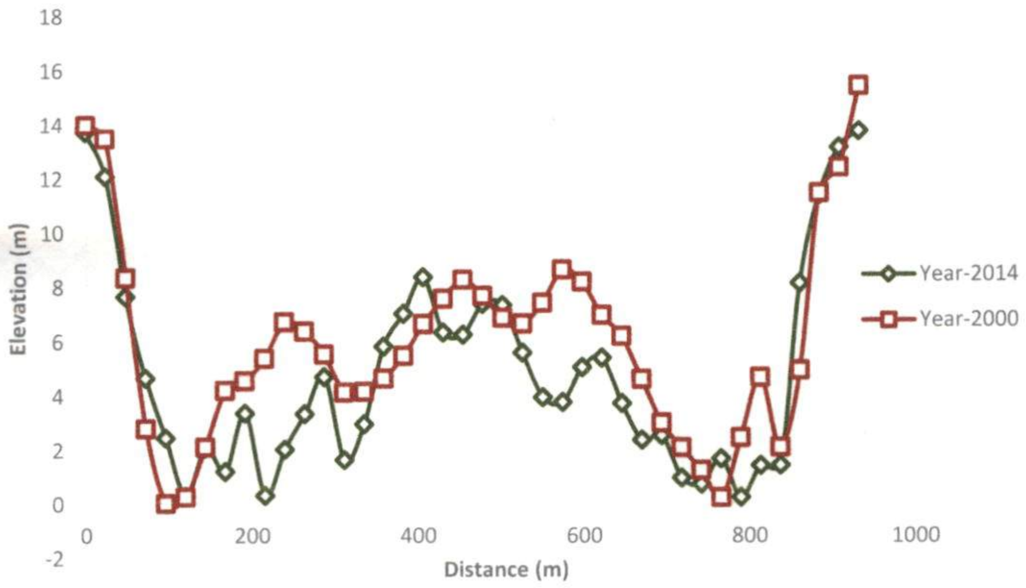

Fig. 4. 1 Cross profile of section A during 2000 and 2014

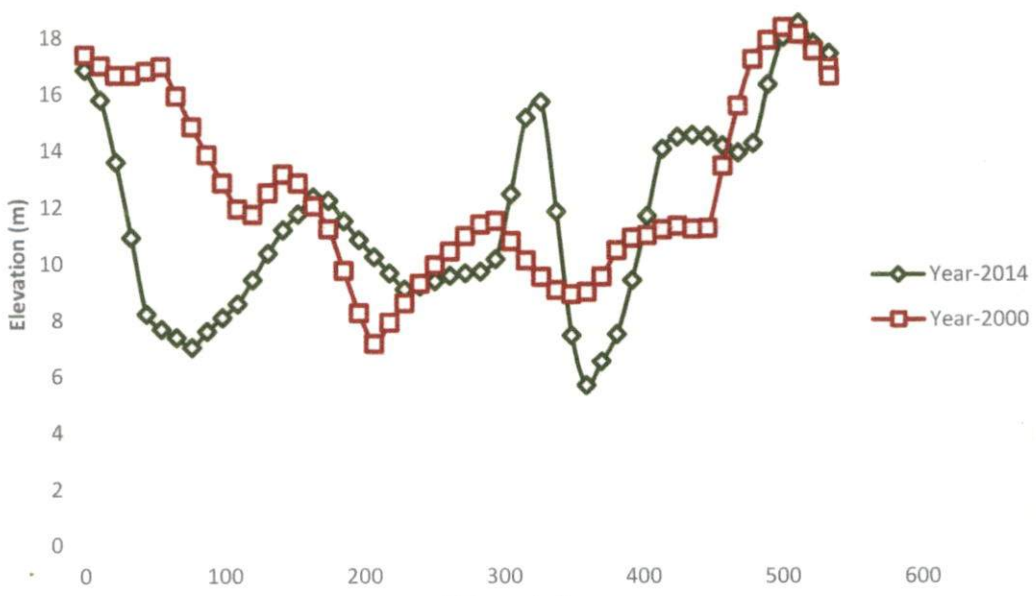

Fig. 4. 2 Cross profile of section B during 2000 and 2014

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4.2.3 Cross Section C

Mallur Kadavu located at 10^0 50' 24.8" N, 76^0 01' 20.0" E is selected as section C. The cross profile showed a great variation in the profile for the two-time periods. This section was usually known for the excessive sand mining. Cross profile showed a high rate of channel widening as well as scouring. Cross section had within it accumulation of sand which reflected similar to a sand dune. The average change in depth was 0.30 m. The rate of erosion was 136.52 m^2 in area. Fig. 4.3 represents the change in depth along the section C.

4.2.4 Cross Section D

Section D is known as Keltron Kadavu and located at 10^0 49' 56.0" N, 76^0 01' 34.1" E. The cross profile showed a great change in between these two periods. The profile made it clear that high scouring and channel widening had taken place in the section. The section was an area of extreme sand mining which had caused such drastic changes in the channel. The average change in depth was 0.24 m. The change in area was 115.73 m^2. It was caused by channel erosion. The section had an undulating river bed. It was seen that the rate of scouring of bed was more than compared to rate of channel widening. Sand mining was one of the reason for such a large rate of downcutting. The value of sand was the reason for such illegal actions. Even the local people used to extract sand from the river for their household needs. Collection of sand from the riverbed in sacks was a common picture in these areas, especially during summer season. Fig. 4.4 represents the change in depth along the section D.

4.2.5 Cross Section E

Section E is located at 10^0 49' 51.4" N, 76^0 02' 12.1" E and it is known as Kattadi Kadavu in the field. The cross profile of the section indicated that the area was filled with many depressions and small sand dunes. The average change in depth along this section was very less, about 0.05 m. It was clear by examining the cross profile. There was a slight increase in the area of about 30.66 m^2 due to deposition. No any significant channel widening in the section was noted. A slight amount of scouring of channel bed was seen. Sand mining was one of the reason for the scouring but the effects are balanced by the river action because of which no great change was visible in the section during these time periods. The existing depressions were the result of extreme sand mining in the past. Due to high restrictions, nowadays the rate of mining is less which had maintained the bed elevation. Fig. 4.5 represents the change in depth along the section E.

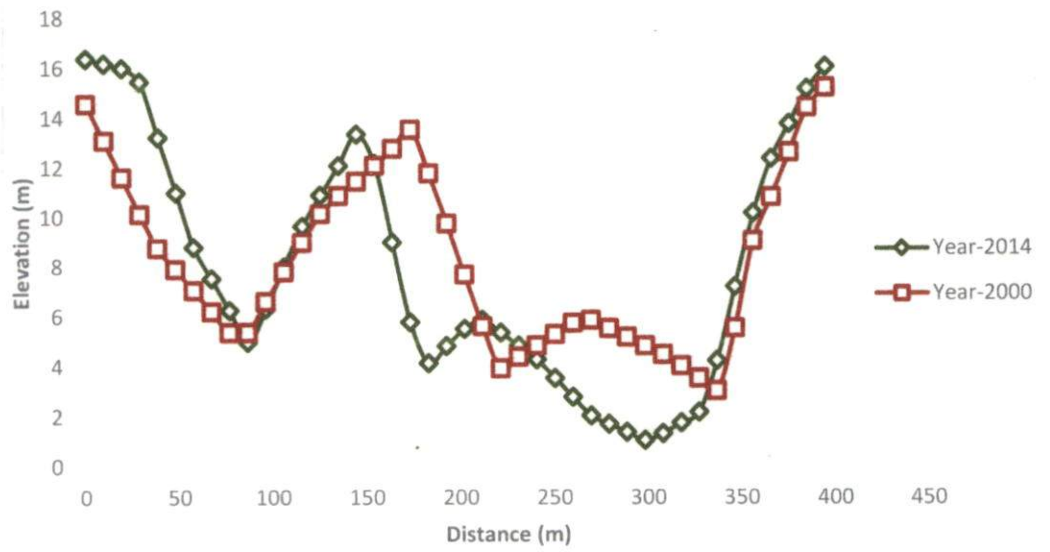

Fig. 4. 3 Cross profile of section C during 2000 and 2014

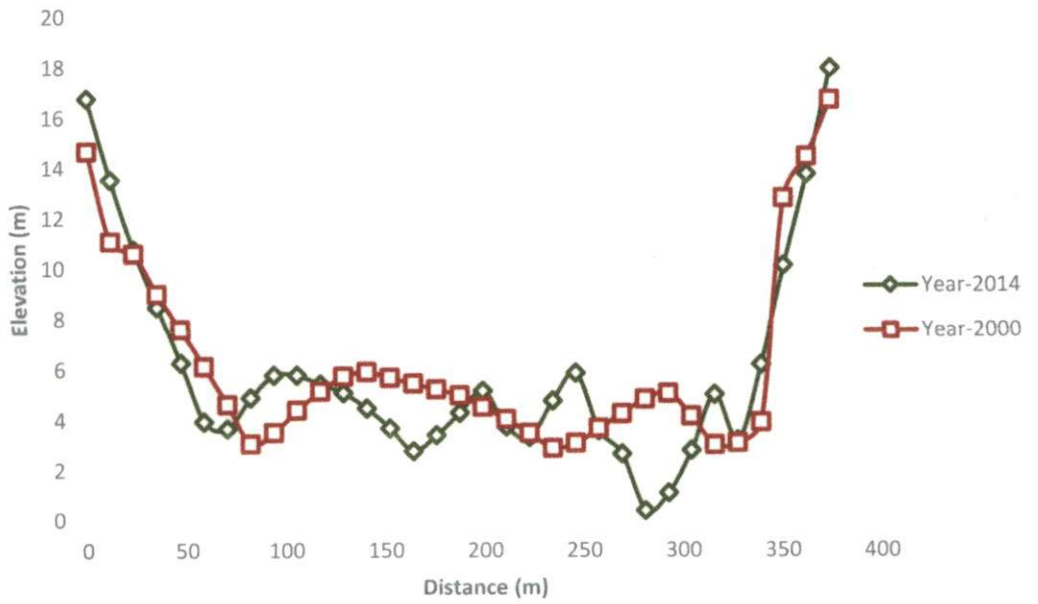

Fig. 4. 4 Cross profile of section D during 2000 and 2014

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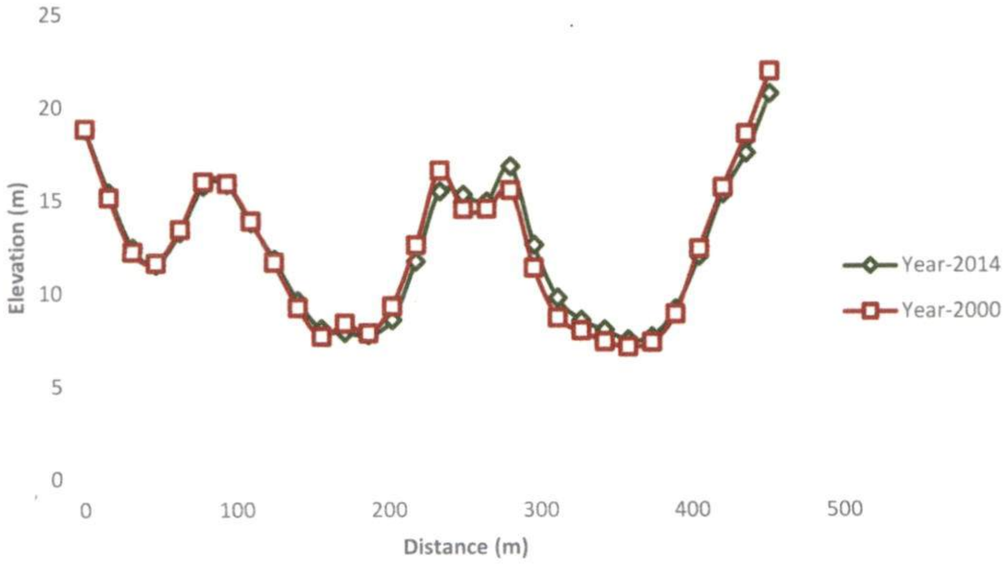

Fig. 4. 5 Cross profile of section E during 2000 and 2014

4.2.6 Cross Section F

Section F is known as Kumbidi Ner Kadavu and is located at 10^0 50' 18.2" N, 76^0 02' 22.5" E. Cross profile of the section indicated that the area was highly undulating which explained that the river bed had been disturbed largely. The average change in depth was 0.47 m. The area had suffered erosion of about 178.94 m^2. The morphological changes in this section was caused mainly due to scouring which had change the bed elevation greatly. A slight amount of channel widening was also seen in the section, but the rate was less compared to the downcutting. The information provided by the nearby people explained the reason of downcutting to be the illegal sand mining. These Kadavus were and are still sites of sand extraction. Among the all other anthropogenic activities the sand extraction was the main reason of destruction of the river channel. Fig. 4.6 represents the change in depth along the section F, it makes clear the picture of the section.

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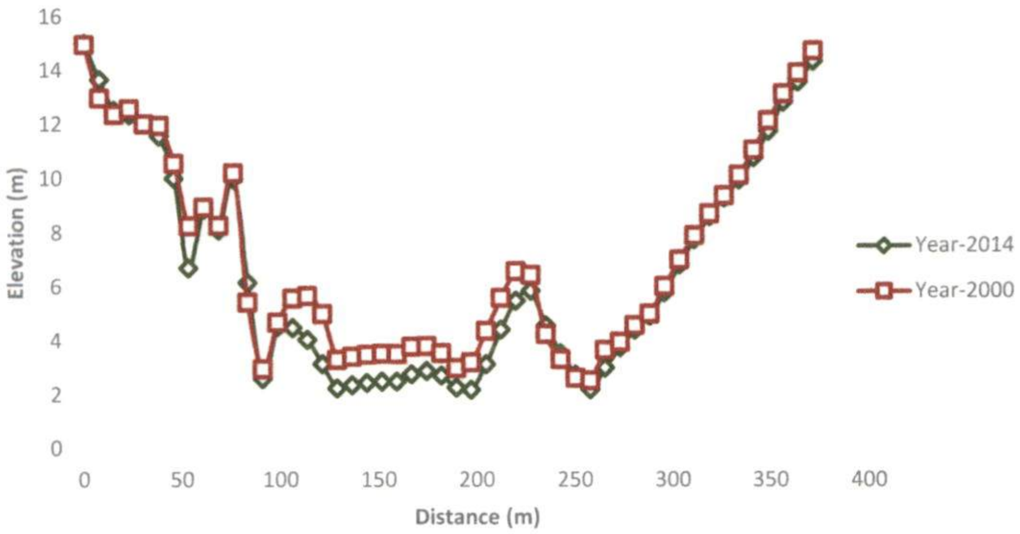

Fig. 4. 6 Cross profile of section F during 2000 and 2014

4.2.7 Cross Section G

Section G located at 10^0 50' 44.4" N, 76^0 02' 16.0" E represents the School Kadavu in the field. Cross profile of the section indicated that section had undergone channel widening and scouring. The change in depth was caused due to channel scouring due to sand extraction. Channel widening was the result due to lateral erosion. The average change in depth of the section was found to be 0.07 m. Channel eroded about 27.015 m^2. Details obtained from local people justified the reason of change was due to illegal sand mining. Fig. 4.7 represents the change in depth along the section G.

4.2.8 Cross Section H

Section H is located at 76°1'1.411"E, 10°51'5.092"N. The cross profile of the section denoted that no change had been occurred in this area. It concluded that the effect of sand mining in this area was insignificant. Inaccessibility to the area can be considered as the reason of no change in the bed elevation of the section. The section was a highly undulating area which depicted that the area had undergone changes in the past due to anthropogenic activities. The area also had sand accumulation in the middle part of the section which was due to high rate of deposition in the river channel. Fig. 4.8 represents the change in depth along the section H.

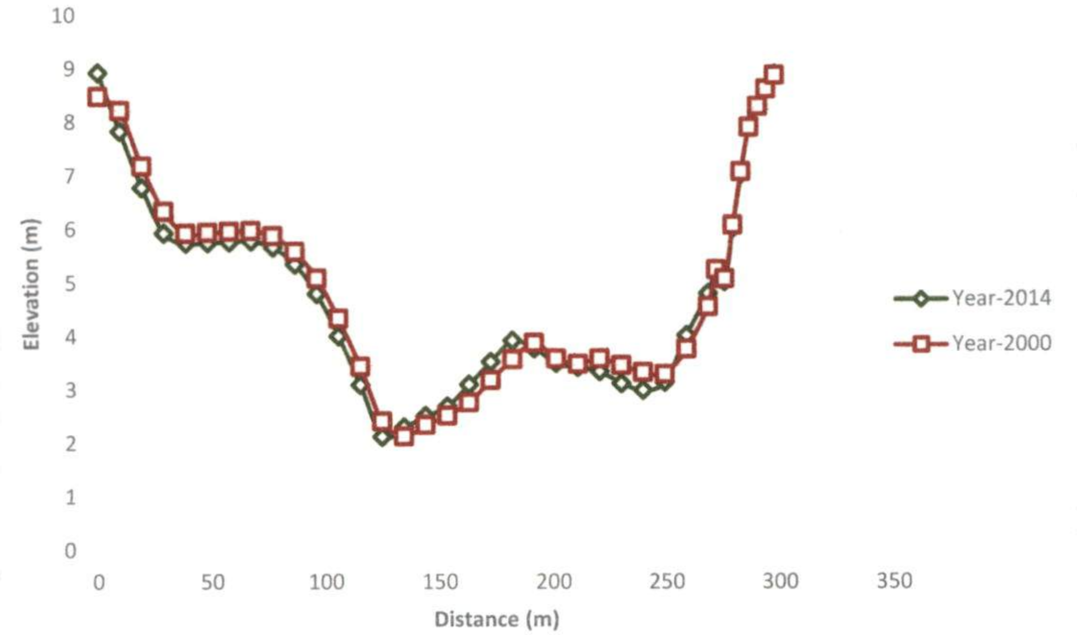

Fig. 4. 7 Cross profile of section G during 2000 and 2014

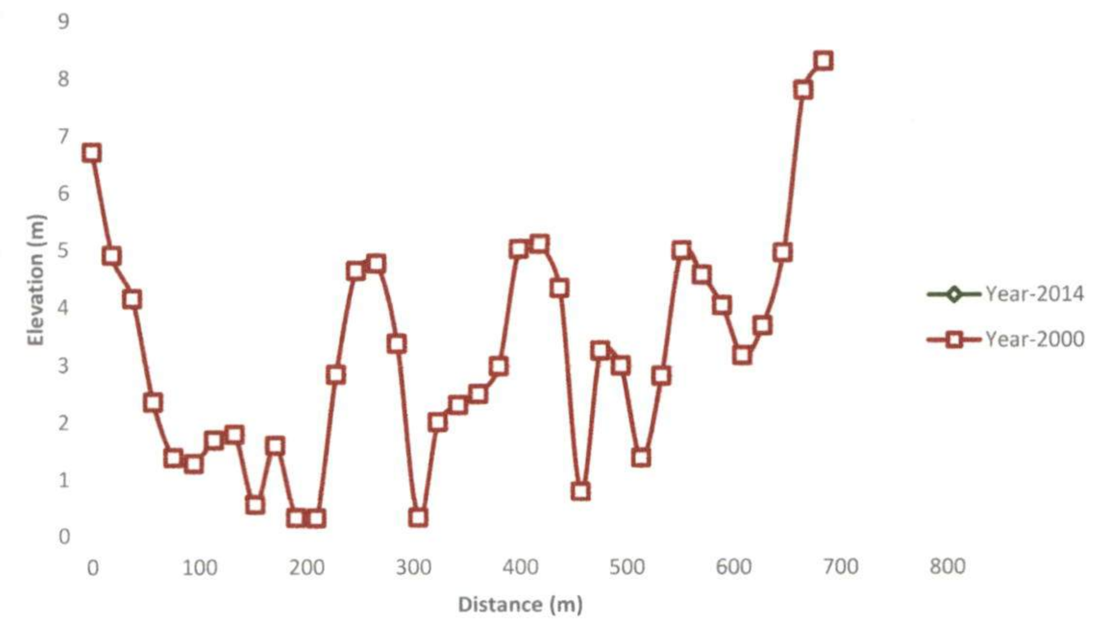

Fig. 4. 8 Cross profile of section H during 2000 and 2014

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4.2.9 Cross Section I

The location of section is given by 10^0 50' 30.9" N, 76^0 03' 21.4" E. The section is known as Ummathur Kadavu in the actual field. The section was also a site of illegal sand mining during the past. Even though the sand mining is still continued in this section the rate is less than compared to the past. The cross profile showed that change was caused only in the middle of the bed. No significant changes were seen along the banks. The change in average depth indicated the change in bed elevation due to scouring. Scouring was mainly caused by sand extraction. The average rate of change in depth was found to be 0.55 m. There was a reduction in area of about 140.93 m^2. Reduction in area denoted that erosion had been occurred in this section continuously. Sand extraction that causes scouring of river bed was a main reason for the erosion. No any significant change in the width of the channel as well as in the elevation of banks was seen. It implied that the rate of bank erosion was less compared to the channel erosion in this section. Fig. 4.9 represents the change in depth along the section I, which clearly depicts the above results.

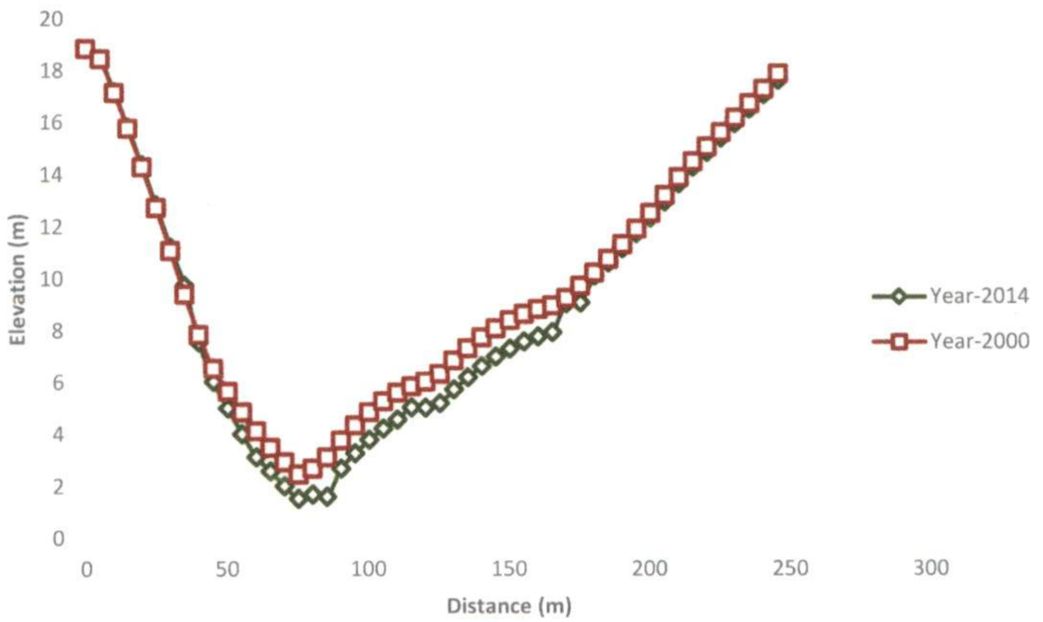

Fig. 4. 9 Cross profile of section I during 2000 and 2014

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4.2.10 Cross Section J

The location of section J is given by 76°2'52.511"E, 10°50'41.292"N. This section also did not show any changes in the cross profile. It indicated that the area was not significantly affected by the sand mining. It also indicated that the rate of mining in these areas was too less to create a change in the cross profile during the considered time periods. Even then the channel bed had remained undulated. It was considered to be the effect of sand extraction in the past. It can also be concluded that no cross-sectional changes had occurred in this section between 2000 to 2014 may be due to the inaccessibility of vehicles to these areas. Fig. 4.10 represents the change in depth along the section J.

4.2.11 Cross Section K

Section K is located at 10^0 49’ 53.1” N, 76^0 05’ 21.7” E. It is known as Koottakadavu. The section was also a known area for illegal sand mining. The section of river channel was quite undulating. The cross-sectional details indicated only a slight change in the undulation as well as depth and area. The section had been eroded about 150.82 m^2. The average change in depth along the channel section was 0.43 m. The changes were more near to banks than in the centre of the channel. Sand mining had caused scouring of river bed in a great amount. In this section, no significant channel widening could be found. The main cause of cross sectional change in this section was due to scouring of bed only and it was mainly caused by sand mining. Fig. 4.11 represents the change in depth along the section K.

4.2.12 Cross Section L

Section L is located at 76°10'20.359"E, 10°47'42.253"N. The cross profile of the section denoted that only a less change had occurred in the whole section. No significant channel widening had been noted in the section but a small amount of deposition was visible in some parts of the area. The average change in depth of the section was 0.05 m. The section had a deposition of 22.05 m^2 in area. The change was seen only in a small area of the section. The result denoted that the section was not affected by sand mining in a high rate. Fig. 4.12 represents the change in depth along the section L.

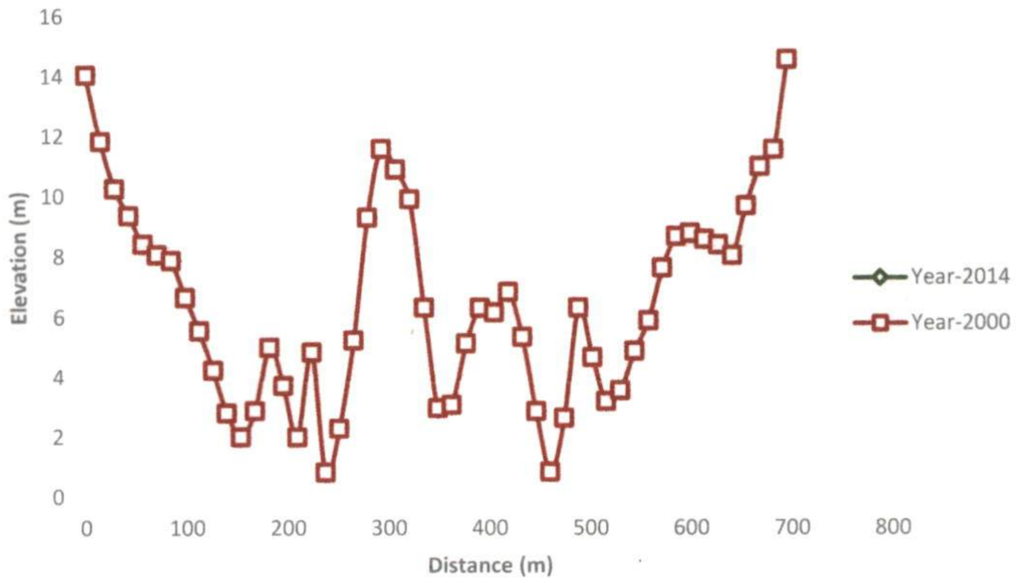

Fig. 4. 10 Cross profile of section J during 2000 and 2014

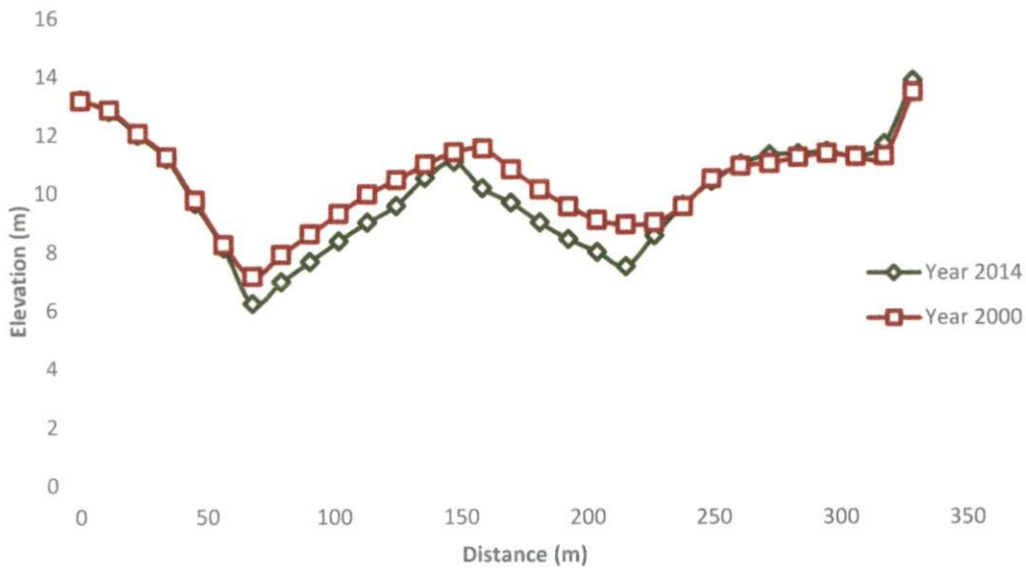

Fig. 4. 11 Cross profile of section K during 2000 and 2014

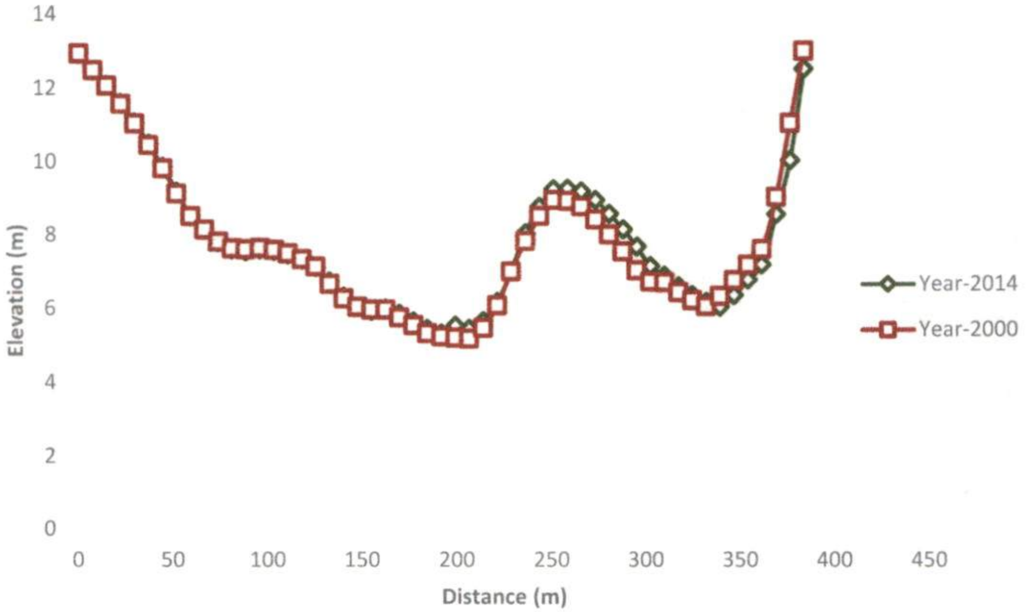

Fig. 4. 12 Cross profile of section L during 2000 and 2014

4.2.13 Cross Section M

The location of section M is given by 76°8'37.057"E, 10°48'32.25"N. The cross profile resulted denoted that this section also had no any significant changes during the time period 2000-2014. The section had almost flat bed with a little undulation to the left bank. There were signs of downcutting in the channel which may had occurred during the river action and human activities in the past. No any significant channel widening also was noted along the section. All these results stated that overall change in the section was zero and was balanced by the river itself. Fig. 4.13 represents the change in depth along the section M.

4.2.14 Cross Section N

The section N was in the DEM imagery forms to be the Thrithala Kadavu in the field. The location of section is 10^0 48' 09.8" N, 76^0 07' 29.2" E. The section was an area known for sand mining. Information provided by the local people indicated that the section was an area concentrated by illegal sand mining. Nowadays due to high restriction, rate of sand mining is less in this area. After examining the cross-sectional change during 2000 and 2014 we could note that a small amount of deposition had occurred in the particular area. An area increase of 113.24 m^2 was found out. An average change in depth of 0.44 m was seen along the section. Cross sectional profile of the area denoted that the section was slightly undulating It showed that there was no considerable change in the depth of the cross section. The increase in area was due to the increase in width of the channel section during these time periods. The channel had been widened slightly due to lateral erosion which was one of the reason along with sand mining to cause change in the cross section. Fig. 4.14 represents the change in depth along the section N.

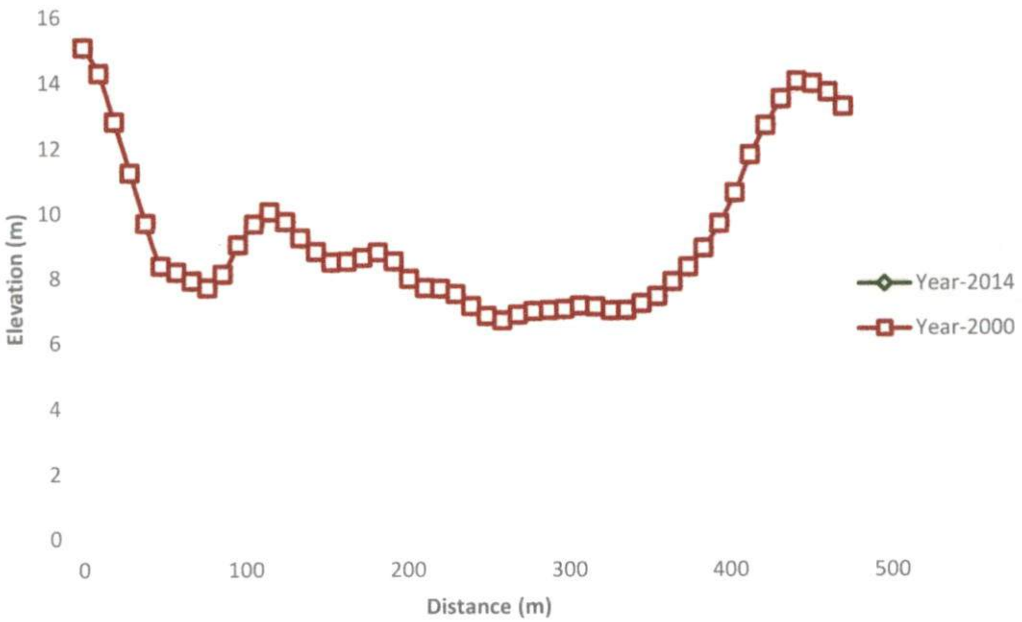

Fig. 4. 13Cross profile of section M during 2000 and 2014

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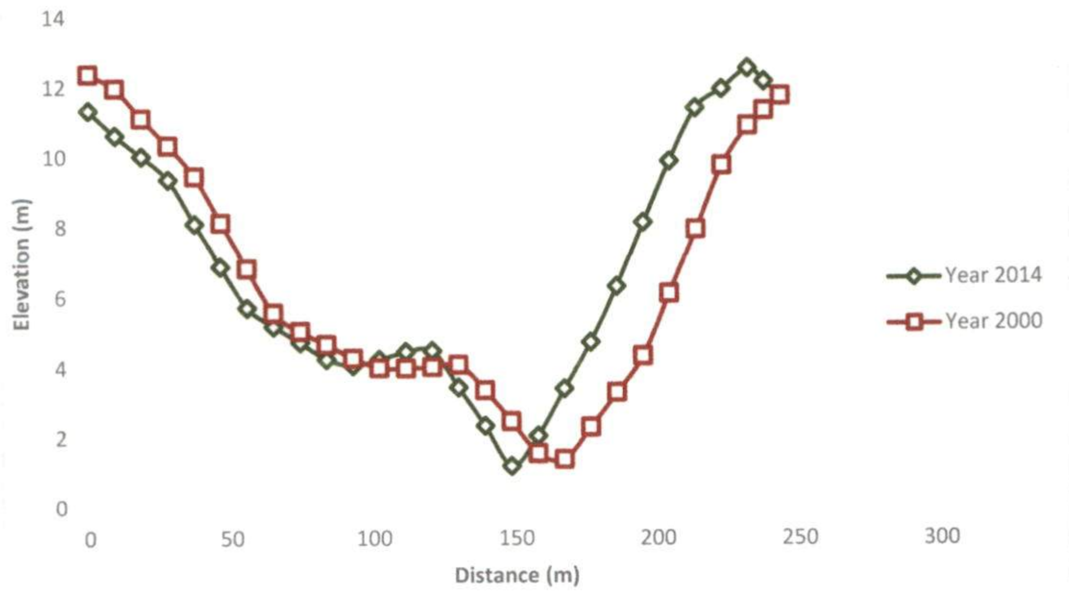

Fig. 4. 14 Cross profile of section N during 2000 and 2014

4.2.15 Cross Section O

The location of section O is given by 76°5'36.684"E, 10°49'10.456"N. The present section also showed no change in the cross profile during 2000-2014. It depicted that the section was not affected by sand mining and other anthropogenic activities. It can also be concluded that the change in the channel bed during this time period was balanced by the river action. The section had an undulated bed. It was assumed that the undulations in the channel can be a result of the river action as well as the sand extraction conducted during the past. Fig. 4.15 represents the change in depth along the section O.

4.2.16 Cross Section P

Section P is located at 76°5'15.675"E, 10°50'19.435"N. The cross profile of the section denoted that no change had occurred in the channel depth during 2000-2014. The section was almost flat. The undulations within the section can be regarded as the result of river action as well as due to past sand mining. The river action and anthropogenic activities had no significant effect during the considered period. It concluded that the change that can be occurred was balanced by the river action itself. Fig. 4.16 represents the change in depth along the section P.

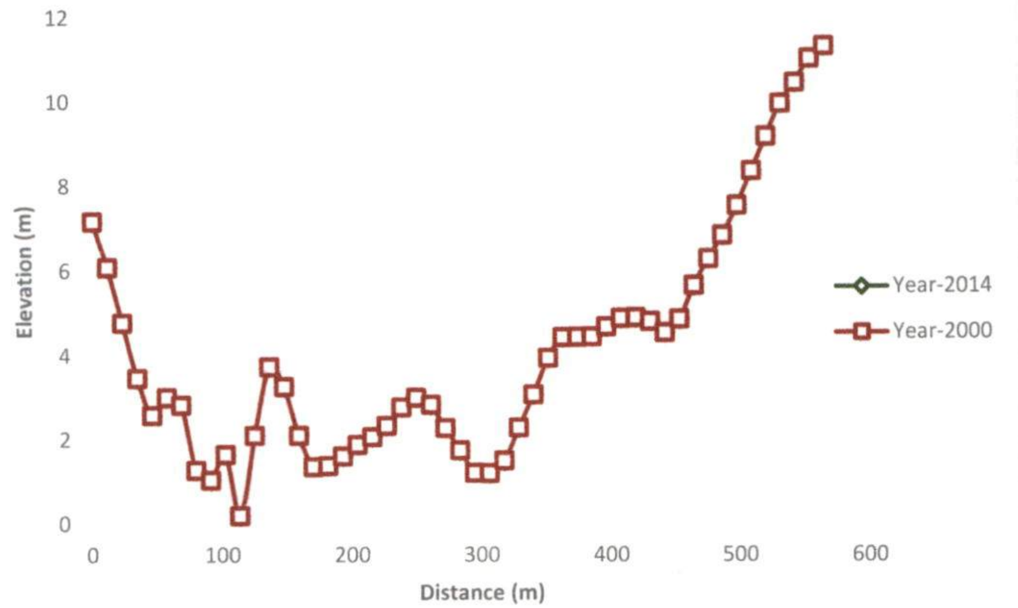

Fig. 4. 15 Cross profile of section O during 2000 and 2014

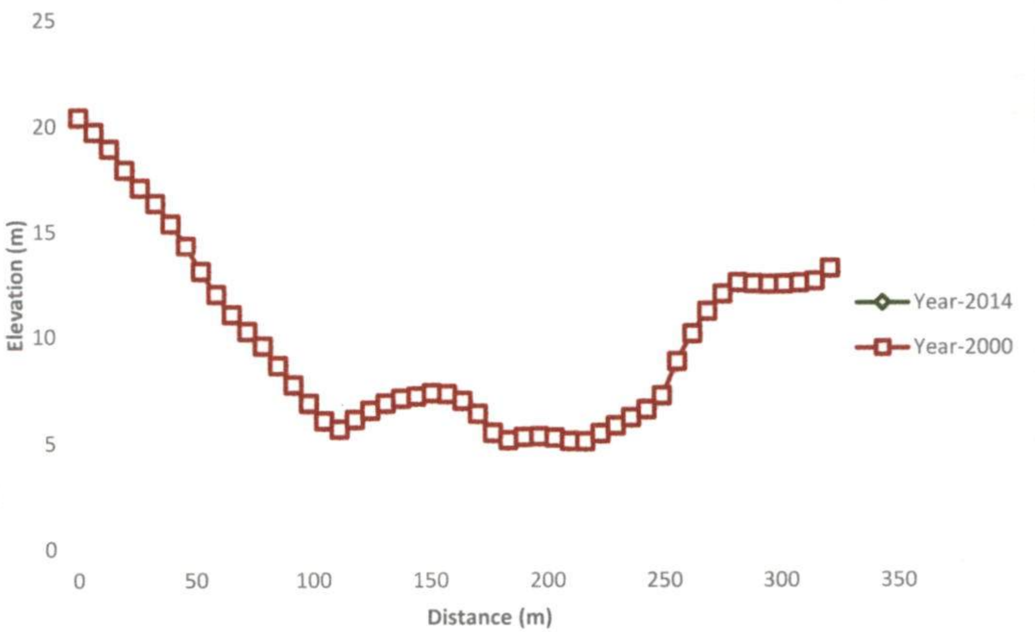

Fig. 4. 16 Cross profile of section P during 2000 and 2014

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4.2.17 Cross Section Q

The location of section Q is given by 76°6'6.562"E, 10°48'45.2"N. The section had an undulated cross profile but the change in the section was zero. It indicated that during 2000-2014, the section had not been affected by the anthropogenic activities and it could also be considered that the changes were balanced by the river action. The undulations that were present in the section represented the change that had occurred in the channel during the past periods due to river action as well as other human activities. The section also had not experienced any significant channel widening too. In all means it was concluded that the cross-sectional changes in the section was completely unnoticeable. Fig. 4.17 represents the change in depth along the section Q.

4.2.18 Cross Section R

Section R is located at 76°6'45.877"E, 10°48'27.833"N. The section resulted a cross profile with no change in the elevation values during the time period 2000-2014. The section had a channel bed with varying bed slope. Small sand dunes were also seen in the middle of the channel section. The ups and downs the river channel was the result of river action and other human activities that occurred in the past. As the present cross profile denoted no change, the result depicted the river action and other human activities did not affect the channel bed severely. It can also be considered that the changes were balanced by the river itself. Fig. 4.18 represents the change in depth along the section R.

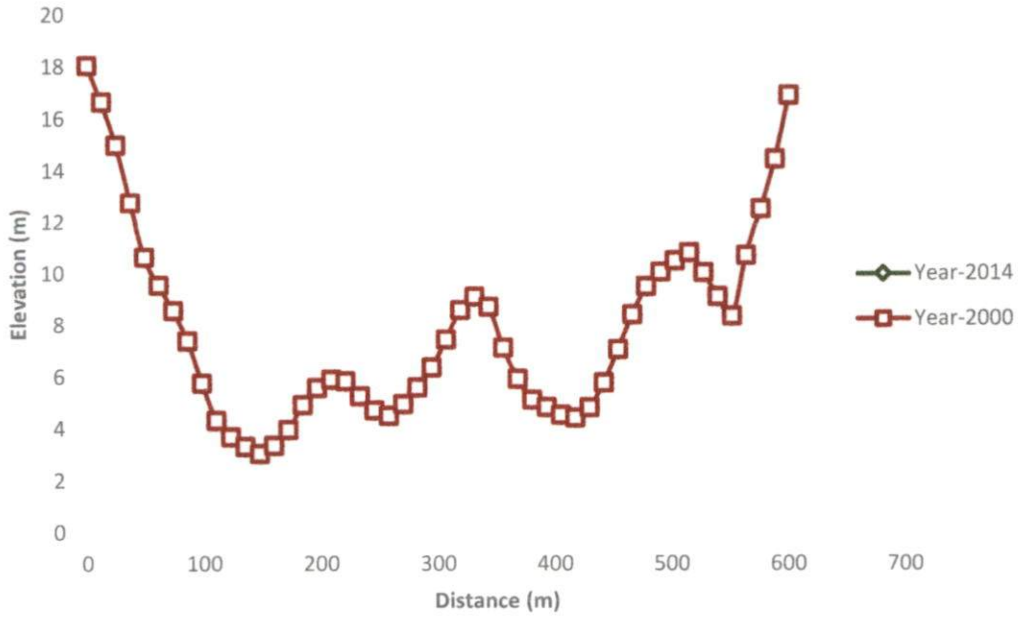

Fig. 4. 17 Cross profile of section Q during 2000 and 2014

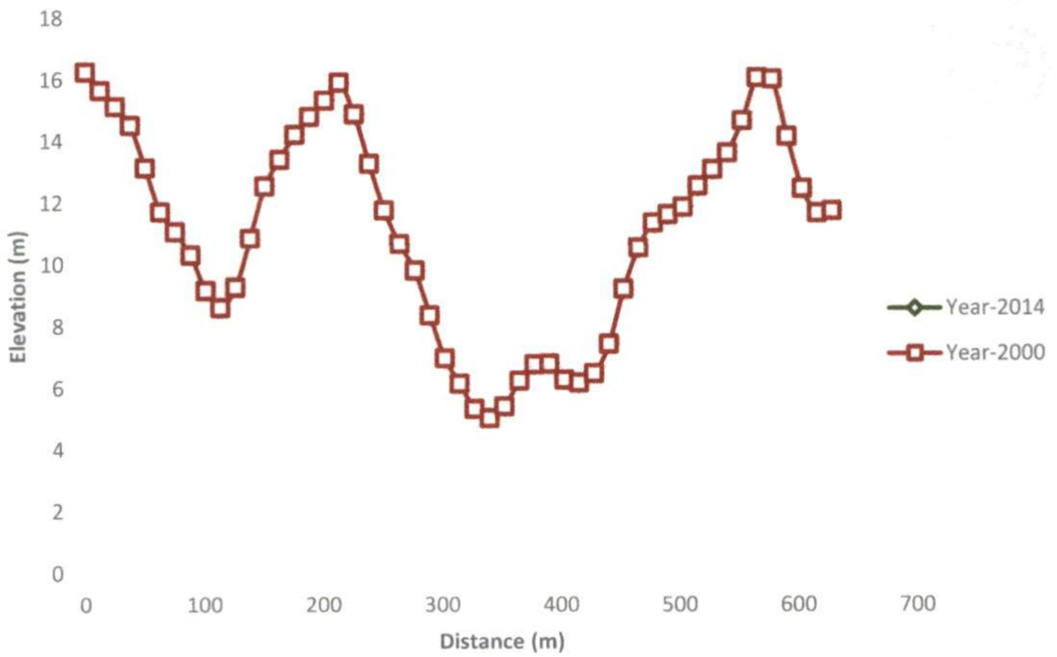

Fig. 4. 18 Cross profile of section R during 2000 and 2014

Cross sectional analysis in the 18 sections showed that most of the sections had undergone changes during the considered time period from 2000-2014. It was clear that drastic changes in the section was seen along the reach closer tp Kuttippuram, i.e., the sections from A to G. No significant changes were visible in the other sections. Downstream regions were the areas of severe sand mining which had caused the drastic changes in the bed elevation of the river in the selected sections. The data obtained from satellite imageries had shown great similarity to the field conditions. The highest change in area was observed in the Vellanchery and Nila Park Kadvu. The changes in area was caused mainly by lateral erosion which had caused the widening of channel. Mostly the downstream sections had observed channel widening. Upstream sections had not experienced any channel widening. Aravindan (2002) had reported that the endless mining had deepened the river bed. Santhosh and Sreeja (2012), Abubakar and Bashir (2013) had reported extreme sand mining as the reason of channel scouring and bank erosion mainly in downstream which had deepened the river bed and widened the river channel. The main cross-sectional changes in the river reach of Kuttippuram to Pattambi were the channel deepening and channel widening. These changes are highly visible in the sections closer to Kuttippuram of the reach.

4.3 ASSESSMENT OF CHANGES IN RIVER BANKS

The reach of Bharathapuzha from Kuttippuram to Pattambi was divided into 18 cross sections. The sections are named from A to R with A as the first section from the upstream section of the river and R as the end section at the endpoint of downstream. The shifting of the channel from 1990 to 2017 along both the banks was measured in 18 cross-sections along the river and the results are presented in Table 4.2. The maximum shift took place in the left bank along the section K (431.328 m) and in the right bank along the section D (287.126 m). The line diagram in Fig. 4.19 indicates the shift in the banks of river reach during the time period between 1990 and 2017. The negative values (-) indicate the shifting of banks to south and the positive values (+) indicate the shifting of banks to north.

As the river Bharathapuzha is flowing from North to West from the Anamalai hills in the Western Ghats to the Arabian sea, the shifting of the bank line indicates the shift of river. It showed a trend of shift towards the northern side. Except the section O all other sections showed a northern shift whereas O section exhibited a southward shift. Shift in both banks in opposite direction was only detected in the section O. Left bank shifted towards north about 170.407 m and right bank towards south about 155 m. Large variation in shift between banks had occurred along the section K in the same direction. Right bank shifted about 431.92 m and left bank by 195.42 m. The bank line shifting was identified significantly towards north along the Kuttippuram to Pattambi stretch of the Bharathapuzha river. Similar studies were reported by Reza and Islam, (2016).

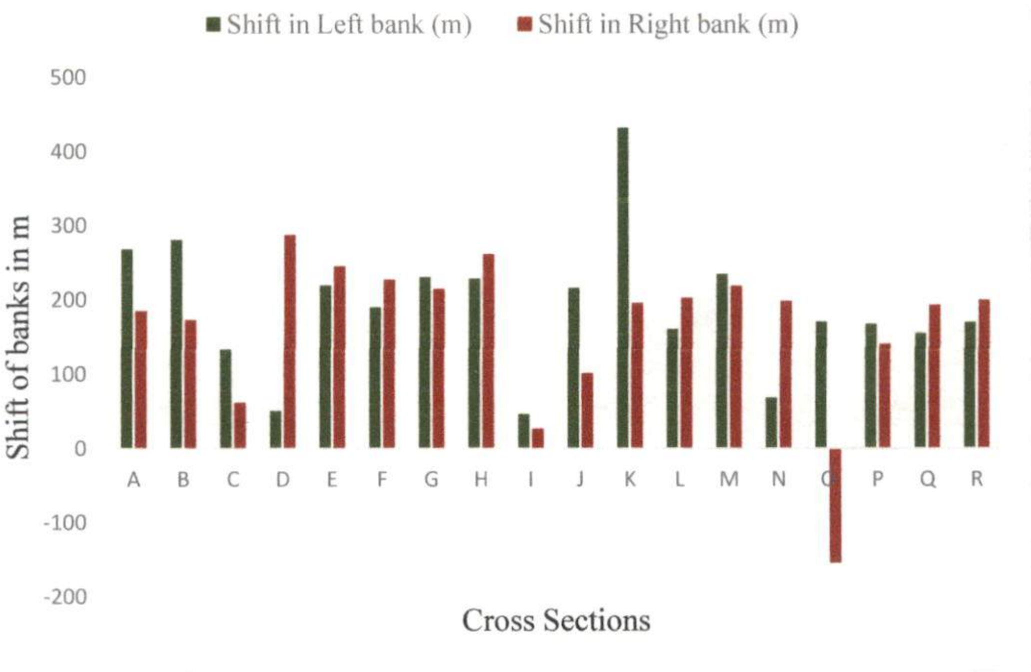

Fig. 4. 19 Shifting along both banks of the Kuttippuram to Pattambi reach of Bharathapuzha river from 1990 to 2017

Table 4. 2 Shifting along both banks of the river reach from 1990 to 2017

Sections	Shift in Left bank (m)	Shift in Right bank (m)
A	267.911	185.208
B	280.633	173.057
C	133.321	61.664
D	50.375	287.126
E	219.231	244.673
F	189.788	226.953
G	230.58	214.235
H	228.203	261.276
I	46.302	26.458
J	215.601	101.237
K	431.928	195.242
L	160.429	202.178
M	234.165	218.381
N	68.101	198.134
O	170.407	-155
P	167.468	140.316
Q	154.823	192.748
R	169.545	199.427

4.3 ANALYSIS OF CHANNEL ENLARGEMENT AND LATERAL MIGRATION

The reach of Bharathapuzha from Kuttippuram to Pattambi was divided into 18 cross sections. The change in the width of the channel from 1990 to 2017 along both the banks was measured for 18 cross-sections along the river and the results are presented in Table 4.3. The Table 4.3 shows the variation of width of the channel in different cross-sections along with the total change in width and the rate of change for the two-time periods 1990 and 2017. From Fig. 4.20 we can see the pattern of rate of change in width of the channel in different sections from 1990 to 2017, which represents the channel enlargement in the reach considered. It was found that in the sections D, J, K and N a great change in width had occurred. The negative values (-) indicate the decrease in width and the positive values (+) indicate the increase in width of the channel. The great channel enlargement had been witnessed along the sections J and K. The channel enlargement was highest in the along section K (227.657 m) and it was lowest in the section G (3.826 m) with a rate of change of 8.432 m/year and 0.142 m/year respectively. It indicated the highest and lowest rate of change among the sections. Section D showed the highest decrease in width, i.e., 241.455 m with a rate of change of about 8.943 m/year. The total rate of change in width along the reach during 1990 to 2017 was 4.98 m/year and the average rate of change was 0.277 m/year. In the present study, the width of the Bharathapuzha river along the Kuttippuram to Pattambi reach had changed from 1990 to 2017. Similar studies were reported by Gogoi and Goswami, (2013).

During the past 27 years due to erosion and deposition bank line migration along the Kuttippuram to Pattambi reach of Bharathapuzha river has occurred. Erosion is predominant in the left bank of the river because of which the width of the river has decreased significantly. Fig. 4.21 shows the total amount of erosion and deposition along both banks of the Bharathapuzha river and these are 32768.55 km^2 and 20205.40 km^2 respectively. Fig. 4.22 represents the erosion and deposition along the banks of the river reach.

Table 4. 3 Channel enlargements along both banks of the Bharathapuzha river from 1990 to 2017 in the Kuttippuram to Pattambi reach

Sections	Year-1990	Year-2017	Total width change	Rate of change in width (m/year)
A	720.991	635.009	85.982	3.185
B	1031.331	933.109	98.222	3.638
C	958.728	900.871	57.857	2.143
D	487.262	728.717	-241.455	-8.943
E	325.731	343.338	-17.607	-0.652
F	811.906	858.987	-47.081	-1.744
G	557.326	553.5	3.826	0.142
H	257.99	291.061	-33.071	-1.225
I	615.157	595.313	19.844	0.735
J	589.558	462.844	126.714	4.693
K	674.534	446.877	227.657	8.432
L	292.111	328.939	-36.828	-1.364
M	680.122	662.847	17.275	0.640
N	462.418	592.588	-130.17	-4.821
O	651.148	635.035	16.113	0.597
P	290.929	260.08	30.849	1.143
Q	469.315	498.612	-29.297	-1.085
R	352.57	366.686	-14.116	-0.523
Total rate of change (m/year)				4.989
Average rate of change (m/year)				0.277

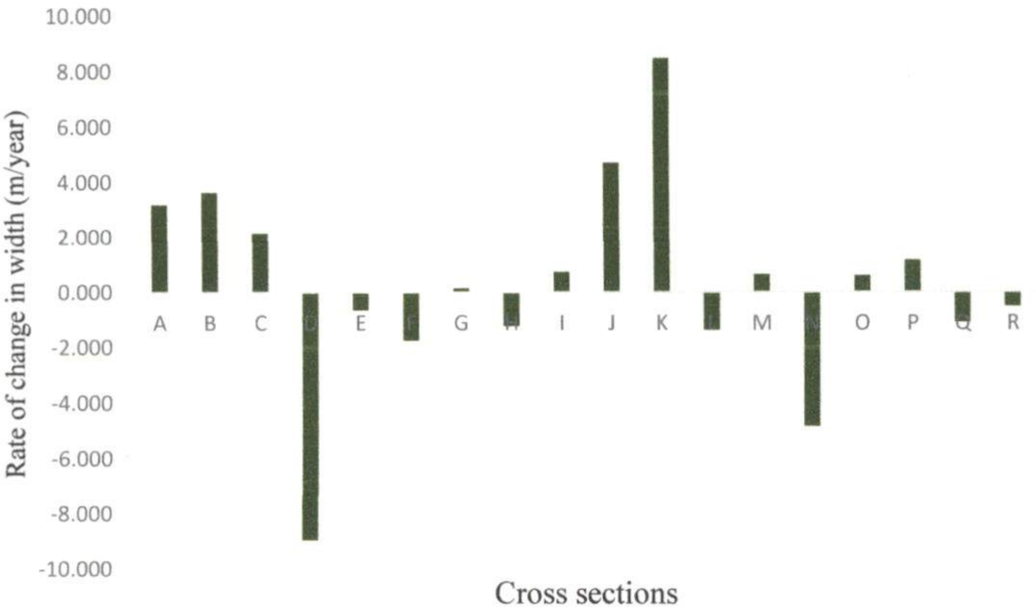

Fig. 4.20 Rate of change in width in the Kuttippuram to Pattambi reach of river from 1990 to 2017

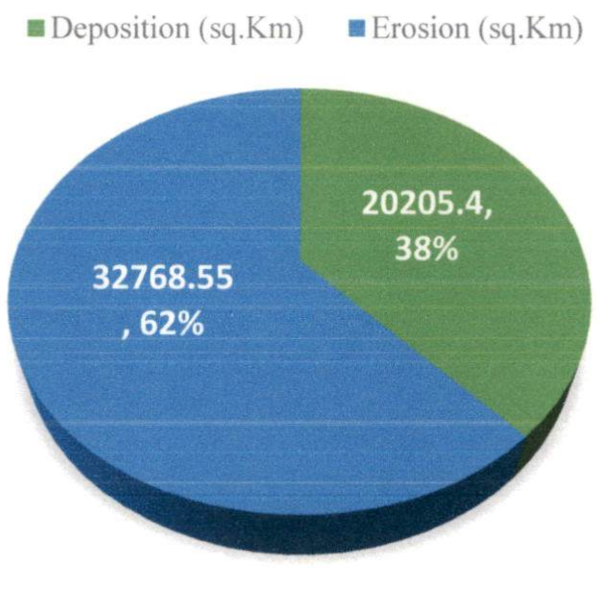

Fig. 4.21 Total erosion/ deposition along the banks of Kuttippuram to Pattambi reach of Bharathapuzha river from 1990 to 2017

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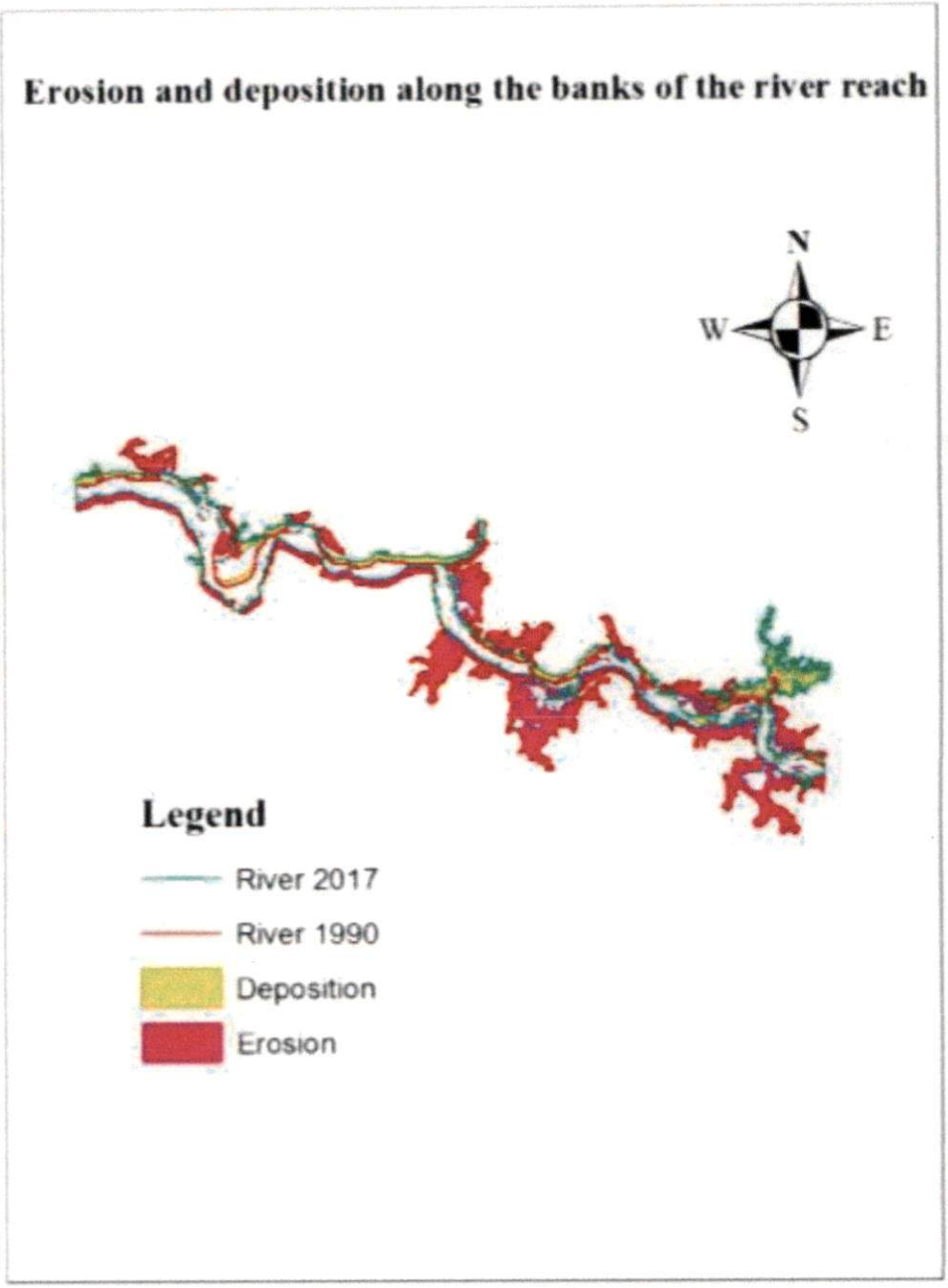

Fig. 4. 22 Erosion and deposition along both banks of Kuttippuram to Pattambi reach of Bharathapuzha river (1990 to 2017)

Summary and conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Rivers, the fundamental component of lifescape and landscape, have been perceived to evolve as a result of many consistent geological processes and interactions. River channels form the most important component in a river ecosystem. Elements of river channel are planform, cross-sectional shape and channel slope which constitute the morphological characters of rivers. Rivers continuously change their shape and reform their channels by eroding the channel boundary and through reworking and deposition of sediments. There exists a balance between the erosive power of the flow and the resistance, of the bed and bank material to erosion. They have been the focus of human activity since early civilizations. As a result, most of the rivers in the world have been altered to levels, often beyond their natural resilience capability.

Among various types of human interventions, indiscriminate extraction of sand and gravel is the most disastrous one, as it threatens the very existence of the riverine ecosystem. Commercial sand extraction from river sources is a global phenomenon. Rapid economic growth and the resulting boom in construction has caused in mushrooming of river sand mining activities. Globally, between 47 and 59 billion tonnes of material is mined every year of which sand and gravel account for the largest share. Bharatapuzha River in Kerala is a great victim of illegal sand mining.

Mining has a direct impact on the stream's physical characteristics, such as channel geometry, bed elevation, substratum composition and stability, in-stream roughness of the bed, flow velocity, discharge capacity, sediment transport capacity, turbidity, temperature etc. Alteration or modification of the above attributes may cause hazardous impact on ecological equilibrium of riverine regime. For conservation and sustainable utilization of resources, proper assessment has to be made on the availability of resources in the river channels and related alluvial sources.

Fluvial geomorphological surveys have become increasingly popular over the last decade as a tool to support sustainable river management. River morphology is the study of the interactions between river channel forms and processes at a range of space and time scales. However, a reliance on field-based approaches limits their wide-spread application at the network scale which is needed to meet current regulatory obligations Use of remote sensing technology coupled with Geographical Information System (GIS) is a quick means of gathering latest accurate information, economically. Integration of Remote sensing and GIS have greatly increased objectivity and efficiency of fluvial geomorphological investigations.

The mining activity is particularly high in the stretch between Pattambi and Kuttippuram of Bharathapuzha river, as the steepness decreases in this reach. Considering this fact, the river reach between Pattambi and Kuttippuram was selected as the study area. The study was carried out to assess the morphological changes as well as the spatial and temporal variations along the reach due to sand mining.

The feasibility of using remotely sensed elevation data in the form of DEM (Digital Elevation Model) for studying the morphological changes of the river was evaluated by finding the difference between the cross-sectional area of the river obtained by actual measurement and that obtained from DEM. Total station survey was conducted at 21 locations in seven Kadavus in order to obtain the actual cross-sectional data for determining the accuracy using the DEM for the determination of the river cross-section. The cross-sectional areas of the river obtained from the DEM showed an average percentage deviation of 4.32 per cent with that obtained from the field measured values. These result show that elevation profile obtained from DEM's have sufficient accuracy for use in morphological analysis of rivers.

CARTOSAT and SRTM DEM imageries of the year 2014 and 2000 respectively were used to evaluate the effect of sand mining on the morphology of the river reach by analysing the cross-sectional details. Thematic Mapper (TM) imageries from LANDSAT 4-5 and Operational Land Imager (OLI) imageries from LANDSAT 8 pertaining to the time periods 1990 and 2017 respectively were used to analyse the spatial and temporal variations of channel in the reach considered. The analysis and assessment of satellite imageries were carried out using the ArcGIS 10.5 software. The DEM imageries were mosaiced and projected to WGS_1984_UTM ZONE 43N coordinates. The study area was extracted using 'Extraction by mask' tool. The cross-section profile graphs were generated from the line features drawn across the river channel as sections using Elevation profile add-in. The Elevation Profile add-in toolbar allows to easily create profile graphs by drawing lines across the sections on the display in ArcGIS. The then generates the profile graphs and tables. The morphological changes of the river were then calculated by comparing the cross-section profiles obtained for the years 2000 and 2014. The spatial and temporal variations in river morphology were analysed by extracting the bank line using Normalized Difference Water Index (NDWI) and overlaying the extracted bank lines. The change in width and the shift in banks of the river features of 1990 and 2017 quantified the channel enlargement and the lateral migration.

The analysis of the morphological changes in the reach with respect to cross section showed that highest change was at Nila Park Kadavu and the lowest change was at School Kadavu. The positive values of shift in bank lines had which indicated the drifting of the river direction towards the north and negative values denoted the shift towards south. The impact of sand mining analysed with respect to cross- sectional area revealed that Vellanchery Kadavu was greatly affected and the maximum change in this section due to erosion was 968.98 m^2. School Kadavu experienced the least impact due to sand mining. Channel enlargement in the reach varied from 0.52 - 8.43 m/year and the average rate of change in width was 0.28 m/ year. The study depicted that the impact of sand mining was high at areas closer to Kuttippuram.

Thus, the objectives of this study to assess the morphological changes as well as the spatial and temporal variations along the reach due to sand mining using

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remote sensing and Geographical Information Systems (GIS) helped to identify the areas with severe sand mining. The river morphological study using remote sensing and GIS techniques provided realistic information about the morphological changes along Kuttippuram to Pattambi stretch of Bharathapuzha river and this method can be successfully used for mapping and monitoring river morphological changes.

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Appendices

APPENDIX A

Cross sectional details of the 18 sections taken across the reach

Table A. 1. Cross sectional details of section A

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)	Cross sectional area of river bed in the year 2014 (m^2)	Cross sectional area of river bed in the year 2000 (m^2)
0.00	13.74	14.01	-0.27	309.18	329.05
23.93	12.11	13.50	-1.39	236.61	261.48
47.85	7.67	8.36	-0.69	147.82	133.71
71.78	4.69	2.82	1.87	85.72	34.39
95.71	2.48	0.05	2.42	33.50	4.07
119.63	0.32	0.29	0.04	29.07	28.94
143.56	2.11	2.13	-0.03	39.99	76.04
167.49	1.23	4.22	-2.99	55.35	105.31
191.41	3.39	4.58	-1.19	44.69	119.40
215.34	0.34	5.40	-5.06	28.70	145.12
239.27	2.06	6.73	-4.67	64.77	157.03
263.19	3.36	6.40	-3.04	96.71	142.93
287.12	4.73	5.55	-0.83	76.41	116.15
311.05	1.66	4.16	-2.50	55.57	99.75
334.97	2.98	4.18	-1.20	105.53	105.86
358.90	5.84	4.67	1.17	153.98	121.52
382.83	7.03	5.49	1.54	184.24	145.22
406.75	8.37	6.65	1.72	176.00	170.16
430.68	6.35	7.58	-1.23	150.76	189.53
454.61	6.26	8.27	-2.01	163.22	190.86
478.53	7.39	7.69	-0.30	176.17	174.19
502.46	7.34	6.87	0.47	154.84	161.88
526.39	5.60	6.66	-1.05	114.53	168.35
550.31	3.97	7.42	-3.45	92.77	192.01
574.24	3.79	8.63	-4.85	105.87	201.26
598.17	5.06	8.19	-3.12	125.23	181.28
622.10	5.40	6.97	-1.56	109.33	157.54
646.02	3.74	6.20	-2.47	73.35	129.60
669.95	2.40	4.63	-2.23	59.28	91.53
693.88	2.56	3.02	-0.46	42.46	61.34
717.80	0.99	2.11	-1.12	20.99	40.35
741.73	0.76	1.27	-0.50	29.36	18.35
765.66	1.69	0.27	1.42	23.46	32.85
789.58	0.27	2.48	-2.21	20.51	85.75
813.51	1.44	4.69	-3.25	34.66	81.41
837.44	1.45	2.12	-0.66	114.59	84.45

861.36	8.12	4.94	3.18	233.57	196.16
885.29	11.40	11.45	-0.05	293.49	285.32
909.22	13.13	12.40	0.74	321.45	332.57
933.14	13.74	15.40	-1.67	0.00	0.00
		Total	**-41.47**	**4383.73**	**5352.71**
		Average change in elevation (m)	**-1.036655**		
		Change in cross sectional area (m^2)	**-968.98**		

Table A. 2. Cross sectional details of section B

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	16.85	17.40	-0.55	177.72	187.27
10.89	15.80	17.00	-1.21	160.07	183.30
21.78	13.61	16.67	-3.06	133.64	181.45
32.66	10.94	16.66	-5.72	104.37	182.27
43.55	8.23	16.82	-8.59	86.64	183.94
54.44	7.68	16.97	-9.29	82.07	179.13
65.33	7.39	15.93	-8.54	78.53	167.53
76.21	7.04	14.84	-7.81	79.72	156.18
87.10	7.61	13.85	-6.24	85.47	145.45
97.99	8.09	12.87	-4.78	90.79	135.09
108.88	8.58	11.95	-3.36	98.11	129.00
119.76	9.44	11.75	-2.31	107.88	132.11
130.65	10.38	12.52	-2.14	117.50	139.82
141.54	11.21	13.17	-1.96	125.05	141.65
152.43	11.77	12.85	-1.09	131.39	135.56
163.31	12.37	12.05	0.32	133.96	126.80
174.20	12.24	11.24	0.99	129.35	114.35
185.09	11.52	9.76	1.76	121.78	98.04
195.98	10.85	8.25	2.60	114.86	83.90
206.86	10.25	7.16	3.09	108.46	82.07
217.75	9.67	7.91	1.76	102.18	89.93
228.64	9.10	8.61	0.49	99.63	97.50
239.53	9.20	9.30	-0.10	101.24	104.85
250.41	9.39	9.96	-0.56	103.29	111.07
261.30	9.58	10.45	-0.87	104.83	116.67
272.19	9.68	10.99	-1.31	105.65	121.84
283.08	9.73	11.39	-1.66	108.37	124.75
293.96	10.18	11.52	-1.35	123.28	121.58
304.85	12.47	10.81	1.66	150.42	113.97

315.74	15.16	10.12	5.04	168.12	107.06
326.63	15.72	9.54	6.18	150.13	101.35
337.51	11.86	9.08	2.78	105.17	97.99
348.40	7.46	8.93	-1.46	71.51	97.57
359.29	5.68	9.00	-3.32	66.40	100.94
370.18	6.52	9.54	-3.02	76.34	109.00
381.07	7.50	10.48	-2.98	92.14	116.49
391.95	9.42	10.92	-1.49	114.98	119.39
402.84	11.70	11.01	0.68	140.19	121.01
413.73	14.06	11.22	2.84	155.33	122.81
424.62	14.48	11.34	3.13	158.00	122.94
435.50	14.55	11.24	3.31	158.20	122.52
446.39	14.52	11.27	3.25	156.16	134.55
457.28	14.17	13.45	0.72	152.89	158.01
468.17	13.91	15.58	-1.66	153.31	178.63
479.05	14.25	17.24	-2.99	166.49	191.36
489.94	16.34	17.91	-1.58	187.05	197.55
500.83	18.02	18.38	-0.35	199.02	198.72
511.72	18.53	18.13	0.40	197.87	194.14
522.60	17.81	17.53	0.28	191.98	187.68
533.49	17.45	16.94	0.51	7.46	7.18
533.92	17.44	16.63	0.81	0.00	0.00
		Total	**-48.74**	**6134.98**	**6673.95**
		Average change in elevation (m)	**-0.94**		
		Change in cross sectional area (m^2)	**-538.98**		

Table A. 3. Cross sectional details of section C

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	16.37	14.57	1.80	156.79	133.26
9.63	16.18	13.09	3.09	155.00	119.00
19.27	16.00	11.61	4.38	151.48	104.75
28.90	15.45	10.13	5.32	138.13	90.96
38.53	13.23	8.75	4.48	116.70	80.22
48.17	11.00	7.90	3.10	95.36	72.05
57.80	8.80	7.05	1.74	78.61	63.88
67.43	7.52	6.21	1.32	66.33	55.70
77.07	6.25	5.36	0.89	54.06	51.66
86.70	4.98	5.37	-0.39	54.31	57.63
96.33	6.30	6.60	-0.30	68.82	69.37

105.97	7.99	7.80	0.18	84.89	80.87
115.60	9.64	8.99	0.65	98.91	92.12
125.23	10.90	10.14	0.76	110.69	101.20
134.87	12.08	10.87	1.21	122.50	107.49
144.50	13.35	11.44	1.91	122.87	113.29
154.13	12.16	12.08	0.08	101.87	119.67
163.77	8.99	12.77	-3.78	71.12	126.63
173.40	5.78	13.52	-7.74	47.78	121.81
183.03	4.14	11.77	-7.62	43.19	103.59
192.67	4.82	9.74	-4.92	49.73	83.94
202.30	5.50	7.69	-2.19	54.76	64.01
211.93	5.87	5.60	0.26	54.03	45.85
221.57	5.35	3.92	1.43	49.03	39.95
231.20	4.83	4.38	0.45	43.90	44.37
240.83	4.28	4.84	-0.55	37.66	48.76
250.47	3.53	5.29	-1.75	30.43	53.12
260.10	2.78	5.74	-2.95	23.23	55.85
269.73	2.04	5.86	-3.82	17.99	54.77
279.37	1.70	5.51	-3.81	14.84	51.45
289.00	1.38	5.17	-3.79	11.78	48.12
298.63	1.06	4.82	-3.76	11.54	44.78
308.27	1.33	4.47	-3.14	14.85	40.94
317.90	1.75	4.03	-2.27	18.90	36.38
327.53	2.17	3.53	-1.35	30.87	31.58
337.17	4.24	3.03	1.21	55.08	41.25
346.80	7.20	5.53	1.67	83.63	70.20
356.43	10.16	9.04	1.12	108.43	95.59
366.07	12.35	10.81	1.54	125.62	112.72
375.70	13.73	12.60	1.14	138.95	129.95
385.33	15.12	14.38	0.73	149.89	142.38
394.97	16.00	15.17	0.83	0.00	0.00
		Total	**-12.86**	**3064.57**	**3201.10**
		Average change in elevation (m)	**-0.30**		
		Change in cross sectional area (m^2)	**-136.53**		

Table A. 4. Cross sectional details of section D

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)	Cross sectional area of river bed in the year 2014 (m^2)	Cross sectional area of river bed in the year 2000 (m^2)
0.00	16.77	14.67	2.10	177.31	150.63
11.70	13.54	11.07	2.46	142.14	126.77
23.40	10.76	10.59	0.16	112.46	114.57
35.10	8.46	8.99	-0.52	86.16	96.94
46.81	6.26	7.58	-1.32	59.75	80.21
58.51	3.95	6.13	-2.18	44.52	62.89
70.21	3.66	4.62	-0.96	50.01	45.00
81.91	4.89	3.07	1.82	62.38	38.48
93.61	5.78	3.51	2.27	67.56	46.23
105.31	5.77	4.39	1.38	65.51	55.76
117.01	5.43	5.14	0.29	61.47	63.59
128.72	5.08	5.73	-0.65	55.87	68.05
140.42	4.47	5.90	-1.43	47.65	67.69
152.12	3.68	5.67	-2.00	37.72	65.02
163.82	2.77	5.44	-2.67	36.15	62.34
175.52	3.41	5.21	-1.81	44.99	59.58
187.22	4.28	4.97	-0.69	55.21	55.48
198.92	5.16	4.51	0.64	52.02	49.98
210.63	3.74	4.03	-0.29	41.25	43.96
222.33	3.31	3.48	-0.17	47.22	37.30
234.03	4.76	2.89	1.87	62.08	35.02
245.73	5.86	3.09	2.76	55.26	39.59
257.43	3.59	3.67	-0.08	36.59	46.36
269.13	2.66	4.25	-1.59	17.70	53.12
280.83	0.36	4.83	-4.46	8.39	57.81
292.54	1.07	5.05	-3.98	22.66	53.85
304.24	2.80	4.15	-1.35	45.62	41.90
315.94	4.99	3.01	1.99	47.88	35.66
327.64	3.19	3.09	0.10	54.87	40.87
339.34	6.19	3.90	2.29	95.43	97.76
351.04	10.12	12.81	-2.69	139.76	159.60
362.74	13.77	14.47	-0.70	185.64	182.38
374.45	17.96	16.70	1.26	0.00	0.00
		Total	**-8.16**	**2119.22**	**2234.40**
		Average change in elevation (m)	**-0.24**		
		Change in cross sectional area (m^2)	**-115.17**		

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Table A. 5. Cross sectional details of section E

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)	Cross sectional area of river bed in the year 2014 (m^2)	Cross sectional area of river bed in the year 2000 (m^2)
0.00	18.83	18.84	-0.01	266.55	264.52
15.57	15.41	15.14	0.27	216.68	212.82
31.13	12.43	12.20	0.23	186.40	185.31
46.70	11.52	11.61	-0.09	192.82	194.71
62.27	13.25	13.41	-0.16	225.76	228.78
77.84	15.75	15.98	-0.23	245.86	248.11
93.40	15.84	15.89	-0.06	230.50	231.59
108.97	13.78	13.86	-0.08	199.18	198.45
124.54	11.81	11.63	0.18	166.50	162.34
140.11	9.58	9.22	0.36	137.44	131.55
155.67	8.08	7.68	0.40	124.33	124.99
171.24	7.90	8.38	-0.48	121.91	126.30
186.81	7.77	7.85	-0.08	127.11	133.38
202.38	8.56	9.29	-0.73	157.42	169.91
217.94	11.66	12.54	-0.88	211.18	226.75
233.51	15.47	16.59	-1.12	239.26	242.00
249.08	15.27	14.50	0.77	234.93	225.78
264.65	14.91	14.51	0.41	246.90	233.73
280.21	16.81	15.52	1.29	228.67	208.94
295.78	12.57	11.32	1.25	173.46	155.55
311.35	9.71	8.66	1.05	142.05	129.45
326.92	8.54	7.97	0.57	128.75	119.54
342.48	8.01	7.39	0.62	120.51	112.81
358.05	7.48	7.11	0.37	117.59	112.56
373.62	7.63	7.35	0.28	130.33	126.11
389.19	9.11	8.85	0.27	163.72	164.96
404.75	11.92	12.35	-0.42	212.01	217.99
420.32	15.32	15.66	-0.34	255.53	266.28
435.89	17.51	18.55	-1.04	297.49	315.00
451.46	20.71	21.92	-1.21	0.00	0.00
		Total	**1.36**	**5500.85**	**5470.19**
		Average change in elevation (m)	**0.05**		
		Change in cross sectional area (m^2)	**30.66**		

Table A. 6. Cross sectional details of section F

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)	Cross sectional area of river bed in the year 2014 (m^2)	Cross sectional area of river bed in the year 2000 (m^2)
0.00	15.01	14.95	0.06	108.69	105.86
7.58	13.65	12.97	0.69	99.19	96.03
15.17	12.50	12.36	0.14	94.24	94.49
22.75	12.35	12.56	-0.21	92.35	93.14
30.34	12.00	12.00	0.00	89.31	90.83
37.92	11.55	11.95	-0.40	81.72	85.33
45.51	10.00	10.55	-0.55	63.28	71.30
53.09	6.69	8.25	-1.56	58.97	65.15
60.68	8.86	8.93	-0.07	64.31	65.16
68.26	8.10	8.25	-0.16	68.55	69.95
75.85	9.98	10.19	-0.21	61.14	59.23
83.43	6.14	5.42	0.72	33.12	31.73
91.02	2.59	2.94	-0.35	26.96	28.89
98.60	4.52	4.67	-0.15	34.13	38.84
106.19	4.48	5.57	-1.09	32.31	42.56
113.77	4.04	5.66	-1.62	27.21	40.36
121.36	3.13	4.99	-1.85	20.34	31.38
128.94	2.23	3.29	-1.06	17.38	25.37
136.53	2.35	3.40	-1.05	18.17	26.11
144.11	2.44	3.48	-1.04	18.65	26.52
151.70	2.48	3.51	-1.03	18.83	26.63
159.28	2.48	3.51	-1.02	19.88	27.64
166.87	2.76	3.78	-1.02	21.35	28.76
174.45	2.87	3.80	-0.93	21.15	27.84
182.04	2.70	3.54	-0.83	18.82	24.73
189.62	2.26	2.98	-0.73	16.82	23.42
197.21	2.18	3.19	-1.01	20.10	28.63
204.79	3.12	4.36	-1.24	28.55	37.69
212.38	4.41	5.58	-1.17	37.48	46.04
219.96	5.48	6.56	-1.08	42.89	49.20
227.55	5.83	6.42	-0.58	39.41	40.40
235.13	4.56	4.24	0.32	30.66	28.58
242.72	3.53	3.30	0.22	23.74	22.45
250.30	2.73	2.62	0.12	18.66	19.46
257.88	2.18	2.51	-0.33	19.63	23.35
265.47	2.99	3.64	-0.65	25.58	28.79
273.05	3.75	3.95	-0.20	30.88	32.26
280.64	4.39	4.56	-0.17	35.27	36.20
288.22	4.91	4.99	-0.08	40.54	41.68
295.81	5.78	6.00	-0.22	47.69	49.24

303.39	6.80	6.98	-0.18	55.08	56.31
310.98	7.73	7.87	-0.14	61.86	62.76
318.56	8.58	8.68	-0.10	67.70	68.30
326.15	9.27	9.33	-0.06	72.78	73.64
333.73	9.92	10.09	-0.16	78.33	79.98
341.32	10.73	11.00	-0.27	85.10	87.58
348.90	11.71	12.09	-0.38	92.84	95.46
356.49	12.78	13.08	-0.31	99.71	102.17
364.07	13.52	13.86	-0.34	105.47	108.19
371.66	14.29	14.67	-0.38	0.00	0.00
		Total	**-23.73**	**2386.81**	**2565.61**
		Average change in elevation (m)	**-0.47**		
		Change in cross sectional area (m^2)	**-178.79**		

Table A. 7. Cross sectional details of section G

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	8.92	8.48	0.44	80.17	79.93
9.57	7.82	8.22	-0.39	69.91	73.70
19.15	6.78	7.18	-0.40	60.85	64.70
28.72	5.93	6.34	-0.40	55.90	58.70
38.30	5.74	5.92	-0.18	55.04	56.81
47.87	5.75	5.94	-0.19	55.14	56.97
57.45	5.76	5.96	-0.20	55.28	57.13
67.02	5.78	5.98	-0.19	54.81	56.74
76.60	5.67	5.88	-0.21	52.72	54.86
86.17	5.35	5.58	-0.23	48.57	51.08
95.75	4.80	5.09	-0.29	42.17	45.12
105.32	4.01	4.34	-0.33	33.99	37.21
114.90	3.09	3.44	-0.35	24.93	27.97
124.47	2.12	2.41	-0.29	21.12	21.69
134.05	2.29	2.13	0.17	22.98	21.37
143.62	2.51	2.34	0.17	24.87	23.24
153.19	2.69	2.52	0.17	27.70	25.27
162.77	3.10	2.76	0.34	31.70	28.45
172.34	3.52	3.18	0.34	35.61	32.31
181.92	3.91	3.57	0.35	36.81	35.64
191.49	3.78	3.88	-0.10	34.81	35.71
201.07	3.50	3.58	-0.08	33.10	33.81
210.64	3.42	3.48	-0.06	32.36	33.82

220.22	3.34	3.58	-0.24	30.93	33.68
229.79	3.12	3.45	-0.34	29.23	32.43
239.37	2.99	3.32	-0.33	29.33	31.66
248.94	3.14	3.29	-0.15	34.24	33.77
258.52	4.02	3.76	0.25	42.18	39.81
268.09	4.80	4.55	0.24	18.64	18.19
271.81	5.24	5.24	0.00	19.05	19.15
275.52	5.01	5.07	-0.06	20.48	20.68
279.24	6.01	6.06	-0.05	24.17	24.36
282.95	7.00	7.05	-0.05	27.69	27.74
286.67	7.90	7.88	0.02	30.08	30.01
290.38	8.29	8.27	0.02	31.40	31.33
294.10	8.61	8.59	0.02	32.48	32.42
297.82	8.87	8.85	0.02	0.00	0.00
		Total	**-2.57**	**1360.44**	**1387.46**
		Average change in elevation (m)	**-0.07**		
		Change in cross sectional area (m^2)	**-27.01**		

Table A. 8. Cross sectional details of section H

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**
0.00	6.71	6.71	0.00
19.04	4.90	4.90	0.00
38.08	4.15	4.15	0.00
57.12	2.36	2.36	0.00
76.16	1.38	1.38	0.00
95.20	1.28	1.28	0.00
114.24	1.69	1.69	0.00
133.28	1.79	1.79	0.00
152.32	0.55	0.55	0.00
171.36	1.60	1.60	0.00
190.40	0.32	0.32	0.00
209.44	0.31	0.31	0.00
228.48	2.84	2.84	0.00
247.52	4.63	4.63	0.00
266.56	4.76	4.76	0.00
285.60	3.37	3.37	0.00
304.64	0.33	0.33	0.00
323.68	2.01	2.01	0.00

342.72	2.30	2.30	0.00
361.76	2.49	2.49	0.00
380.80	2.98	2.98	0.00
399.84	5.01	5.01	0.00
418.88	5.10	5.10	0.00
437.92	4.33	4.33	0.00
456.96	0.78	0.78	0.00
476.00	3.24	3.24	0.00
495.04	2.98	2.98	0.00
514.08	1.38	1.38	0.00
533.12	2.80	2.80	0.00
552.16	4.98	4.98	0.00
571.20	4.56	4.56	0.00
590.24	4.03	4.03	0.00
609.28	3.16	3.16	0.00
628.32	3.67	3.67	0.00
647.36	4.94	4.94	0.00
666.40	7.79	7.79	0.00
685.44	8.29	8.29	0.00
		Total	0.00
		Average change in elevation (m)	0.00
		Change in cross sectional area (m2)	0.00

Table A. 9. Cross sectional details of section I

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	18.85	18.85	0.00	93.72	93.67
5.02	18.47	18.45	0.02	89.53	89.40
10.05	17.18	17.14	0.04	82.85	82.61
15.07	15.81	15.75	0.06	75.77	75.42
20.09	14.36	14.28	0.08	68.28	67.81
25.12	12.83	12.72	0.11	60.37	59.77
30.14	11.21	11.07	0.13	52.60	51.40
35.16	9.74	9.39	0.35	43.43	43.28
40.19	7.56	7.84	-0.29	34.11	36.10
45.21	6.03	6.53	-0.50	27.70	30.57
50.23	5.00	5.64	-0.64	22.62	26.32
55.25	4.00	4.84	-0.83	17.89	22.48
60.28	3.12	4.12	-1.00	14.28	19.06

65.30	2.57	3.48	-0.91	11.49	16.06
70.32	2.00	2.92	-0.91	8.86	13.46
75.35	1.52	2.44	-0.92	8.04	12.83
80.37	1.68	2.67	-0.99	8.23	14.47
85.39	1.59	3.10	-1.50	10.70	17.21
90.42	2.67	3.76	-1.09	14.89	20.34
95.44	3.26	4.34	-1.08	17.66	23.05
100.46	3.77	4.84	-1.06	20.04	25.35
105.49	4.20	5.25	-1.05	22.00	27.23
110.51	4.56	5.59	-1.03	24.07	28.70
115.53	5.03	5.84	-0.81	25.23	29.75
120.56	5.02	6.01	-0.99	25.64	30.97
125.58	5.19	6.32	-1.13	27.37	33.07
130.60	5.71	6.84	-1.13	29.88	35.54
135.62	6.19	7.31	-1.12	32.14	37.75
140.65	6.61	7.72	-1.11	34.14	39.67
145.67	6.98	8.08	-1.10	35.86	41.33
150.69	7.30	8.38	-1.08	37.31	42.70
155.72	7.56	8.62	-1.06	38.50	43.80
160.74	7.77	8.82	-1.05	39.41	44.63
165.76	7.92	8.95	-1.03	42.61	45.67
170.79	9.04	9.23	-0.19	45.46	47.56
175.81	9.06	9.71	-0.65	48.10	50.02
180.83	10.09	10.21	-0.12	51.98	52.61
185.86	10.61	10.74	-0.13	54.64	55.34
190.88	11.15	11.30	-0.15	57.43	58.21
195.90	11.72	11.88	-0.16	60.35	61.22
200.93	12.31	12.49	-0.18	63.42	64.46
205.95	12.94	13.17	-0.24	66.69	67.85
210.97	13.62	13.85	-0.23	70.01	71.07
215.99	14.26	14.45	-0.20	73.00	74.00
221.02	14.81	15.01	-0.20	75.80	76.82
226.04	15.37	15.57	-0.21	78.59	79.64
231.06	15.92	16.13	-0.21	81.38	82.45
236.09	16.48	16.70	-0.22	84.18	85.27
241.11	17.04	17.26	-0.22	86.97	88.15
246.13	17.59	17.84	-0.25	0.00	0.00
		Total	**-28.18**	**2195.21**	**2336.15**
		Average change in elevation (m)	**-0.56**		
		Change in cross sectional area (m^2)	**-140.94**		

Table A. 10. Cross sectional details of section J

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)
0.00	14.05	14.05	0.00
13.93	11.83	11.83	0.00
27.86	10.26	10.26	0.00
41.79	9.36	9.36	0.00
55.72	8.42	8.42	0.00
69.65	8.07	8.07	0.00
83.58	7.87	7.87	0.00
97.51	6.65	6.65	0.00
111.44	5.55	5.55	0.00
125.37	4.24	4.24	0.00
139.30	2.80	2.80	0.00
153.23	2.00	2.00	0.00
167.16	2.88	2.88	0.00
181.09	5.00	5.00	0.00
195.02	3.71	3.71	0.00
208.95	1.99	1.99	0.00
222.88	4.84	4.84	0.00
236.81	0.81	0.81	0.00
250.74	2.27	2.27	0.00
264.67	5.23	5.23	0.00
278.60	9.29	9.29	0.00
292.53	11.56	11.56	0.00
306.46	10.88	10.88	0.00
320.39	9.89	9.89	0.00
334.32	6.31	6.31	0.00
348.25	2.96	2.96	0.00
362.18	3.07	3.07	0.00
376.11	5.12	5.12	0.00
390.04	6.30	6.30	0.00
403.97	6.15	6.15	0.00
417.90	6.83	6.83	0.00
431.83	5.34	5.34	0.00
445.76	2.86	2.86	0.00
459.69	0.83	0.83	0.00
473.62	2.63	2.63	0.00
487.55	6.30	6.30	0.00

501.48	4.65	4.65	0.00
515.41	3.18	3.18	0.00
529.34	3.55	3.55	0.00
543.27	4.87	4.87	0.00
557.20	5.87	5.87	0.00
571.13	7.61	7.61	0.00
585.06	8.65	8.65	0.00
598.99	8.76	8.76	0.00
612.92	8.55	8.55	0.00
626.85	8.37	8.37	0.00
640.78	8.02	8.02	0.00
654.71	9.66	9.66	0.00
668.64	10.96	10.96	0.00
682.57	11.53	11.53	0.00
696.50	14.52	14.52	0.00
		Total	0.00
		Average change in elevation (m)	0.00
		Change in cross sectional area (m2)	0.00

Table A. 11. Cross sectional details of section K

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	13.20	13.17	0.03	147.38	147.50
11.34	12.80	12.85	-0.05	140.57	141.15
22.67	12.00	12.05	-0.05	131.42	132.04
34.01	11.19	11.24	-0.06	118.14	119.06
45.35	9.65	9.76	-0.11	100.86	102.08
56.68	8.14	8.25	-0.11	81.44	87.36
68.02	6.23	7.16	-0.94	74.83	85.46
79.36	6.97	7.91	-0.94	82.97	93.64
90.69	7.66	8.61	-0.94	90.85	101.52
102.03	8.36	9.30	-0.94	98.43	109.18
113.37	9.00	9.96	-0.96	105.24	115.65
124.71	9.57	10.45	-0.88	113.81	121.49
136.04	10.51	10.99	-0.48	122.37	126.87
147.38	11.08	11.39	-0.32	120.38	129.90
158.72	10.16	11.52	-1.36	112.43	126.60
170.05	9.67	10.81	-1.14	105.85	118.67

181.39	9.00	10.12	-1.12	98.80	111.47
192.73	8.43	9.54	-1.11	93.12	105.53
204.06	8.00	9.08	-1.08	87.88	102.04
215.40	7.51	8.93	-1.42	91.02	101.60
226.74	8.55	9.00	-0.45	102.74	105.10
238.07	9.57	9.54	0.03	113.19	113.50
249.41	10.39	10.48	-0.09	121.21	121.30
260.75	10.99	10.92	0.07	126.39	124.31
272.08	11.31	11.01	0.30	128.36	126.01
283.42	11.34	11.22	0.12	128.94	127.88
294.76	11.41	11.34	0.07	128.48	128.01
306.10	11.26	11.24	0.02	129.97	127.57
317.43	11.67	11.27	0.41	144.68	140.10
328.77	13.85	13.45	0.40	0.00	0.00
		Total	**-13.09**	**3241.75**	**3392.58**
		Average change in elevation (m)	**-0.44**		
		Change in cross sectional area (m^2)	**-150.82**		

Table A. 12. Cross sectional details of section L

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**	**Cross sectional area of river bed in the year 2014 (m^2)**	**Cross sectional area of river bed in the year 2000 (m^2)**
0.00	12.94	12.94	0.00	93.84	93.83
7.38	12.49	12.48	0.00	90.64	90.58
14.76	12.07	12.06	0.01	87.30	87.19
22.14	11.58	11.57	0.02	83.54	83.39
29.52	11.06	11.03	0.02	79.48	79.28
36.90	10.48	10.45	0.03	75.04	74.77
44.28	9.85	9.81	0.04	70.22	69.88
51.66	9.18	9.12	0.05	65.24	65.05
59.04	8.50	8.50	0.00	61.40	61.39
66.42	8.13	8.13	0.00	58.77	58.80
73.80	7.79	7.80	-0.01	56.77	56.90
81.18	7.59	7.62	-0.03	55.85	56.14
88.56	7.54	7.59	-0.05	55.86	56.16
95.94	7.59	7.62	-0.03	55.88	56.09
103.32	7.55	7.58	-0.03	55.38	55.54
110.70	7.46	7.48	-0.02	54.49	54.61
118.08	7.31	7.32	-0.01	53.23	53.29
125.46	7.11	7.12	0.00	51.03	50.81
132.84	6.72	6.65	0.06	48.01	47.65

140.22	6.30	6.26	0.04	45.50	45.34
147.60	6.03	6.03	0.01	44.12	44.19
154.98	5.92	5.95	-0.03	43.88	43.93
162.36	5.97	5.95	0.01	43.57	43.16
169.74	5.84	5.74	0.10	42.33	41.59
177.12	5.63	5.53	0.10	40.79	40.02
184.50	5.42	5.32	0.11	39.59	38.89
191.88	5.31	5.22	0.08	39.93	38.42
199.26	5.52	5.19	0.33	40.39	38.21
206.64	5.43	5.17	0.26	40.84	39.19
214.02	5.64	5.46	0.18	43.51	42.50
221.40	6.15	6.06	0.09	48.46	48.12
228.78	6.98	6.98	0.00	55.36	54.59
236.16	8.02	7.81	0.21	61.87	60.17
243.54	8.74	8.49	0.25	66.31	64.28
250.92	9.23	8.93	0.30	68.17	65.80
258.30	9.25	8.90	0.34	67.95	65.17
265.68	9.17	8.76	0.41	66.79	63.30
273.06	8.93	8.40	0.54	64.54	60.46
280.43	8.56	7.99	0.57	61.58	57.24
287.81	8.13	7.52	0.61	58.23	53.63
295.19	7.65	7.01	0.64	54.51	50.59
302.57	7.12	6.70	0.42	51.59	49.39
309.95	6.86	6.68	0.18	49.57	48.34
317.33	6.57	6.42	0.16	47.64	46.55
324.71	6.34	6.20	0.14	46.09	45.15
332.09	6.15	6.04	0.12	44.92	45.55
339.47	6.02	6.31	-0.29	45.58	48.13
346.85	6.33	6.73	-0.40	48.28	51.27
354.23	6.75	7.16	-0.41	51.36	54.41
361.61	7.17	7.59	-0.42	57.94	61.24
368.99	8.53	9.01	-0.48	68.41	73.85
376.37	10.01	11.01	-1.00	82.91	88.39
383.75	12.47	12.95	-0.48	0.00	0.00
		Total	**2.75**	**2984.44**	**2962.38**
		Average change in elevation (m)	**0.052**		
		Change in cross sectional area (m^2)	**22.06**		

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Table A. 13. Cross sectional details of section M

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)
0.00	15.08	15.08	0.00
9.60	14.29	14.29	0.00
19.21	12.81	12.81	0.00
28.81	11.25	11.25	0.00
38.42	9.69	9.69	0.00
48.02	8.37	8.37	0.00
57.62	8.18	8.18	0.00
67.23	7.91	7.91	0.00
76.83	7.69	7.69	0.00
86.44	8.11	8.11	0.00
96.04	9.02	9.02	0.00
105.64	9.66	9.66	0.00
115.25	10.03	10.03	0.00
124.85	9.74	9.74	0.00
134.46	9.23	9.23	0.00
144.06	8.80	8.80	0.00
153.66	8.48	8.48	0.00
163.27	8.50	8.50	0.00
172.87	8.62	8.62	0.00
182.48	8.79	8.79	0.00
192.08	8.51	8.51	0.00
201.69	7.97	7.97	0.00
211.29	7.69	7.69	0.00
220.89	7.67	7.67	0.00
230.50	7.50	7.50	0.00
240.10	7.13	7.13	0.00
249.71	6.82	6.82	0.00
259.31	6.68	6.68	0.00
268.91	6.86	6.86	0.00
278.52	6.97	6.97	0.00
288.12	6.99	6.99	0.00
297.73	7.03	7.03	0.00
307.33	7.13	7.13	0.00
316.93	7.11	7.11	0.00
326.54	6.99	6.99	0.00
336.14	6.99	6.99	0.00
345.75	7.21	7.21	0.00

355.35	7.42	7.42	0.00
364.95	7.88	7.88	0.00
374.56	8.33	8.33	0.00
384.16	8.91	8.91	0.00
393.77	9.66	9.66	0.00
403.37	10.61	10.61	0.00
412.97	11.77	11.77	0.00
422.58	12.66	12.66	0.00
432.18	13.47	13.47	0.00
441.79	14.01	14.01	0.00
451.39	13.93	13.93	0.00
460.99	13.67	13.67	0.00
470.60	13.24	13.24	0.00
		Total	0.00
		Average change in elevation (m)	0.00
		Change in cross sectional area (m2)	0.00

Table A. 14. Cross sectional details of section N

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)	Cross sectional area of river bed in the year 2014 (m^2)	Cross sectional area of river bed in the year 2000 (m^2)
0.00	11.33	12.38	-1.04	102.06	113.16
9.30	10.62	11.97	-1.35	95.94	107.27
18.59	10.02	11.11	-1.09	90.02	99.66
27.89	9.35	10.33	-0.98	81.02	91.93
37.18	8.08	9.45	-1.37	69.46	81.60
46.48	6.86	8.11	-1.25	58.39	69.34
55.77	5.70	6.81	-1.11	50.52	57.44
65.07	5.17	5.55	-0.38	45.96	49.15
74.36	4.72	5.03	-0.31	41.63	45.00
83.66	4.24	4.66	-0.42	38.59	41.46
92.96	4.06	4.27	-0.20	38.54	38.36
102.25	4.23	3.99	0.24	40.29	37.03
111.55	4.44	3.98	0.46	41.43	37.14
120.84	4.47	4.01	0.46	36.72	37.62
130.14	3.43	4.08	-0.65	26.77	34.52
139.43	2.33	3.34	-1.01	16.34	27.00
148.73	1.18	2.46	-1.28	15.02	18.63
158.02	2.05	1.54	0.50	25.29	13.57
167.32	3.39	1.38	2.02	37.67	17.08
176.61	4.71	2.30	2.41	51.12	25.92

185.91	6.29	3.28	3.01	66.82	35.32
195.21	8.09	4.32	3.77	83.35	48.35
204.50	9.84	6.08	3.76	98.49	64.93
213.80	11.35	7.89	3.46	107.97	81.80
223.09	11.88	9.71	2.17	113.19	95.52
232.39	12.47	10.84	1.63	70.97	63.89
238.17	12.10	11.28	0.82	68.72	66.34
243.94	11.69	11.69	0.00	0.00	0.00
		Total	**12.28**	**1612.30**	**1499.07**
		Average change in elevation (m)	**0.44**		
		Change in cross sectional area (m^2)	**113.24**		

Table A. 15. Cross sectional details of section O

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**
0.00	7.17	7.17	0.00
11.32	6.09	6.09	0.00
22.64	4.77	4.77	0.00
33.95	3.46	3.46	0.00
45.27	2.58	2.58	0.00
56.59	3.00	3.00	0.00
67.91	2.82	2.82	0.00
79.22	1.27	1.27	0.00
90.54	1.04	1.04	0.00
101.86	1.65	1.65	0.00
113.18	0.19	0.19	0.00
124.49	2.10	2.10	0.00
135.81	3.73	3.73	0.00
147.13	3.25	3.25	0.00
158.45	2.10	2.10	0.00
169.76	1.35	1.35	0.00
181.08	1.37	1.37	0.00
192.40	1.60	1.60	0.00
203.72	1.88	1.88	0.00
215.04	2.06	2.06	0.00
226.35	2.32	2.32	0.00
237.67	2.76	2.76	0.00

248.99	2.99	2.99	0.00
260.31	2.82	2.82	0.00
271.62	2.27	2.27	0.00
282.94	1.74	1.74	0.00
294.26	1.21	1.21	0.00
305.58	1.20	1.20	0.00
316.89	1.49	1.49	0.00
328.21	2.28	2.28	0.00
339.53	3.06	3.06	0.00
350.85	3.93	3.93	0.00
362.17	4.41	4.41	0.00
373.48	4.42	4.42	0.00
384.80	4.43	4.43	0.00
396.12	4.66	4.66	0.00
407.44	4.86	4.86	0.00
418.75	4.87	4.87	0.00
430.07	4.78	4.78	0.00
441.39	4.52	4.52	0.00
452.71	4.84	4.84	0.00
464.02	5.62	5.62	0.00
475.34	6.25	6.25	0.00
486.66	6.80	6.80	0.00
497.98	7.50	7.50	0.00
509.29	8.30	8.30	0.00
520.61	9.12	9.12	0.00
531.93	9.90	9.90	0.00
543.25	10.38	10.38	0.00
554.57	10.96	10.96	0.00
565.88	11.25	11.25	0.00
		Total	**0.00**
		Average change in elevation (m)	**0.00**
		Change in cross sectional area (m^2)	**0.00**

Table A. 16. Cross sectional details of section P

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)
0.00	20.42	20.42	0.00
6.55	19.74	19.74	0.00
13.11	18.95	18.95	0.00
19.66	17.95	17.95	0.00
26.22	17.09	17.09	0.00
32.77	16.37	16.37	0.00
39.33	15.40	15.40	0.00
45.88	14.34	14.34	0.00
52.44	13.11	13.11	0.00
58.99	12.02	12.02	0.00
65.55	11.07	11.07	0.00
72.10	10.26	10.26	0.00
78.65	9.59	9.59	0.00
85.21	8.65	8.65	0.00
91.76	7.75	7.75	0.00
98.32	6.88	6.88	0.00
104.87	6.05	6.05	0.00
111.43	5.66	5.66	0.00
117.98	6.11	6.11	0.00
124.54	6.54	6.54	0.00
131.09	6.87	6.87	0.00
137.65	7.10	7.10	0.00
144.20	7.22	7.22	0.00
150.75	7.37	7.37	0.00
157.31	7.32	7.32	0.00
163.86	6.99	6.99	0.00
170.42	6.38	6.38	0.00
176.97	5.50	5.50	0.00
183.53	5.15	5.15	0.00
190.08	5.29	5.29	0.00
196.64	5.33	5.33	0.00
203.19	5.27	5.27	0.00
209.75	5.10	5.10	0.00
216.30	5.08	5.08	0.00
222.85	5.46	5.46	0.00

229.41	5.83	5.83	0.00
235.96	6.21	6.21	0.00
242.52	6.58	6.58	0.00
249.07	7.25	7.25	0.00
255.63	8.85	8.85	0.00
262.18	10.16	10.16	0.00
268.74	11.22	11.22	0.00
275.29	12.03	12.03	0.00
281.84	12.58	12.58	0.00
288.40	12.52	12.52	0.00
294.95	12.50	12.50	0.00
301.51	12.51	12.51	0.00
308.06	12.56	12.56	0.00
314.62	12.64	12.64	0.00
321.17	13.25	13.25	0.00
		Total	**0.00**
		Average change in elevation (m)	**0.00**
		Change in cross sectional area (m^2)	**0.00**

Table A. 17. Cross sectional details of section Q

Distance (m)	**Elevation of river bed in the year 2014 (m)**	**Elevation of river bed in the year 2000 (m)**	**Change in river bed elevation (m)**
0.00	18.04	18.04	0.00
12.28	16.64	16.64	0.00
24.56	14.99	14.99	0.00
36.85	12.77	12.77	0.00
49.13	10.63	10.63	0.00
61.41	9.55	9.55	0.00
73.69	8.56	8.56	0.00
85.97	7.38	7.38	0.00
98.25	5.75	5.75	0.00
110.54	4.31	4.31	0.00
122.82	3.69	3.69	0.00
135.10	3.32	3.32	0.00
147.38	3.04	3.04	0.00
159.66	3.35	3.35	0.00
171.95	3.96	3.96	0.00
184.23	4.91	4.91	0.00
196.51	5.56	5.56	0.00

208.79	5.88	5.88	0.00
221.07	5.82	5.82	0.00
233.36	5.24	5.24	0.00
245.64	4.70	4.70	0.00
257.92	4.49	4.49	0.00
270.20	4.94	4.94	0.00
282.48	5.57	5.57	0.00
294.76	6.34	6.34	0.00
307.05	7.42	7.42	0.00
319.33	8.55	8.55	0.00
331.61	9.07	9.07	0.00
343.89	8.69	8.69	0.00
356.17	7.09	7.09	0.00
368.46	5.90	5.90	0.00
380.74	5.10	5.10	0.00
393.02	4.82	4.82	0.00
405.30	4.52	4.52	0.00
417.58	4.40	4.40	0.00
429.86	4.80	4.80	0.00
442.15	5.75	5.75	0.00
454.43	7.03	7.03	0.00
466.71	8.37	8.37	0.00
478.99	9.46	9.46	0.00
491.27	10.02	10.02	0.00
503.56	10.45	10.45	0.00
515.84	10.75	10.75	0.00
528.12	9.99	9.99	0.00
540.40	9.06	9.06	0.00
552.68	8.31	8.31	0.00
564.97	10.65	10.65	0.00
577.25	12.46	12.46	0.00
589.53	14.36	14.36	0.00
601.81	16.78	16.78	0.00
		Total	**0.00**
		Average change in elevation (m)	**0.00**
		Change in cross sectional area (m^2)	**0.00**

Table A. 18. Cross sectional details of section R

Distance (m)	Elevation of river bed in the year 2014 (m)	Elevation of river bed in the year 2000 (m)	Change in river bed elevation (m)
0.00	16.26	16.26	0.00
12.58	15.65	15.65	0.00
25.15	15.13	15.13	0.00
37.73	14.52	14.52	0.00
50.30	13.13	13.13	0.00
62.88	11.71	11.71	0.00
75.45	11.07	11.07	0.00
88.03	10.31	10.31	0.00
100.60	9.17	9.17	0.00
113.18	8.62	8.62	0.00
125.75	9.27	9.27	0.00
138.33	10.85	10.85	0.00
150.90	12.54	12.54	0.00
163.48	13.41	13.41	0.00
176.05	14.22	14.22	0.00
188.63	14.80	14.80	0.00
201.20	15.33	15.33	0.00
213.78	15.91	15.91	0.00
226.35	14.89	14.89	0.00
238.93	13.27	13.27	0.00
251.50	11.76	11.76	0.00
264.08	10.67	10.67	0.00
276.65	9.81	9.81	0.00
289.23	8.37	8.37	0.00
301.80	6.98	6.98	0.00
314.38	6.15	6.15	0.00
326.95	5.33	5.33	0.00
339.53	5.02	5.02	0.00
352.10	5.42	5.42	0.00
364.68	6.24	6.24	0.00
377.25	6.77	6.77	0.00
389.83	6.79	6.79	0.00
402.40	6.27	6.27	0.00
414.98	6.19	6.19	0.00
427.55	6.48	6.48	0.00
440.13	7.44	7.44	0.00
452.70	9.22	9.22	0.00

465.28	10.55	10.55	0.00
477.85	11.36	11.36	0.00
490.43	11.63	11.63	0.00
503.00	11.87	11.87	0.00
515.58	12.55	12.55	0.00
528.15	13.08	13.08	0.00
540.73	13.62	13.62	0.00
553.30	14.67	14.67	0.00
565.88	16.07	16.07	0.00
578.45	16.02	16.02	0.00
591.03	14.16	14.16	0.00
603.61	12.47	12.47	0.00
616.18	11.68	11.68	0.00
628.76	11.75	11.75	0.00
		Total	**0.00**
		Average change in elevation (m)	**0.00**
		Change in cross sectional area (m2)	**0.000**

ASSESSMENT OF THE IMPACT OF SAND MINING ON THE MORPHOLOGY OF THE SEVERELY AFFECTED REACH OF BHARATHAPUZHA RIVER BETWEEN PATTAMBI AND KUTTIPPURAM USING REMOTE SENSING AND GIS

By

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(2015-18-009)

ABSTRACT OF THESIS

Submitted in partial fulfilment of the requirements for the degree

Master of Technology

In

Agricultural Engineering

(Soil and Water Engineering)

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

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2017

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ABSTRACT

Rivers have been a subject of study by engineers and scientists who have been fascinated by their self-formed geometric shapes and their responses to changes in nature and human interference. Among various types of human interventions, indiscriminate extraction of sand and gravel is the most disastrous one, as it threatens the very existence of the riverine ecosystem. Bharatapuzha River in Kerala is a great victim of illegal sand mining. The effect of over exploitation of instream sand on the river morphology is very important for quantifying its effect and for exploring alternatives. The mining activity is particularly very high in the stretch between Pattambi and Kuttippuram of Bharathapuzha river. Use of remote sensing technology coupled with Geographical Information System (GIS) is a quick means of gathering latest accurate information, economically. The study was undertaken to assess the morphological changes as well as the spatial and temporal variations along the reach due to sand mining. The study utilised DEM imageries to evaluate the effect of sand mining on the morphology of the river reach by analysing the cross-sectional details. LANDSAT imageries were used to analyse the spatial and temporal variations of channel in the reach. The analysis and assessment of satellite imageries were carried out using the ArcGIS 10.5 software. The Elevation Profile add-in toolbar was utilised to create profile graphs by taking sections across the river course in ArcGIS and the morphological changes of the river were calculated by comparing the cross-section profiles. The spatial and temporal variations in river morphology were analysed by extracting the bank lines using Normalized Difference Water Index (NDWI) and overlaying the extracted bank lines. The study revealed that the impact of sand mining was high at areas closer to Kuttippuram. Channel enlargement in the reach was found to be varying from 0.52 - 8.43 m/year. The reach experienced an average rate of change in width of 0.28 m/ year. The shift in bank lines indicated the drifting of the river direction towards the north. From the study, it can be concluded that remote sensing and GIS techniques provided realistic information about the impacts of sand mining on the riverine ecosystem and have sufficient accuracy for use in morphological analysis of rivers.