Letters in Economic Research Updates

PRIME OPEN ACCESS

Volume 1, Issue 1

Research Article

Date of Submission: 06 February, 2025
Date of Acceptance: 28 March, 2025
Date of Publication: 02 April, 2025

Applicability of Geospatial Tools for Long-Term Sediment Deposit Analysis and Identification of Paleo-Channels. A Case Study of Ganga River Basin. Bihar, India

Neeraj Kumar[1*], Deepak Lal[1], Arpan Sheering[1], Ajaz Ahmad[1], Mukesh Kumar[1], Vivekanand Rawat[2], Akash Anand[3], Shakti Suryavanshi[4] and Saroj Kumar[5]

[1]Centre for Geospatial Technologies, Sam Higginbottom University of Agriculture Technology and Sciences, India

[2]Department of Bio-resource Engineering- McGIll University, Montreal, Canada

[3]Civil Engineering Department, Aligarh Muslim University, Aligarh, India

[4]National Institute of Hydrology, Roorkee, India

[5]Bihar Rural Development Society, India

***Corresponding Author**
Neeraj Kumar, Centre for Geospatial Technologies, Sam Higginbottom University of Agriculture Technology and Sciences, India.

Citation: Kumar, N., Lal, D., Sheering, A., Ahmad, A., Kumar, M., et al. (2025). Applicability of Geospatial Tools for Long-Term Sediment Deposit Analysis and Identification of Paleo-Channels. A Case Study of Ganga River Basin. Bihar, India. *Lett Econ Res Updates, 1*(1), 01-13.

Abstract
The river Ganga and its tributaries are important water resources for North India. It has its own ecosystem and also creates a unique biodiversity around its vicinity. It has been found that huge sediment deposits take place in the River Ganga basin from past few decades. The flow area of many rivers is reducing continuously. During the flood, it inundates the large agriculture and urban areas. It caused a huge economic loss along with human death & displacement. The organisation involved in the flood management and related works are facing the difficulties in long term planning and development of mitigation strategies such as river dragging, river training works, flood & disasters management etc. The evidence of sediment deposition is highly required in the public domain to use in overall project development for this basin. Therefore, a study was conducted to estimate the sediment deposit rate and its areas of the basin. Various scientific methods, such as satellite imagery interpretation, digitization, modelling techniques have been used. The result obtained by the study indicates the continuous rise in sediment deposition in the river basin. The detail of the sediment deposit rate, area and locations of the river Gandak, Budhi Gandak, Bagmati, Kamla Balan, Kosi and Mahananda along with the methodology are provided in this manuscript. The methodology developed in the study are tested and reliable for the application on another river basin too.

Keywords: River Sedimentation, Paleo Channels, River Rejuvenation Works and Disaster Management

Introduction
The hydrological cycle is one of the major components of Earth's ecosystem. It includes precipitation, water accumulation, run-off, evaporation, percolation, etc. These phenomena ensure the water distribution in the environment and are also essential for the survival of various organisms on the planet [1]. In the past few decades, due to the rise in

global temperature and other environmental factors, it has been observed that anomalies in precipitation have become more common as compared to previous decades [2]. The number of rainfall events and the days are also changing globally [3]. The phenomena are also responsible for various types of environmental tragedies such as floods, drought, landslides, waterlogging, erosions, etc [4, 5]. In all these tragedies, the flood is one of the most devastating events. Millions of lives are highly affected every year by floods [6]. In India, Bihar is one of the most flood-affected states, and in the past few decades, the flood frequencies have also risen. There are many reasons listed for the flooding, such as heavy precipitation, sudden release of water from dams, clogging of natural drainages, etc., but in the case of the Ganga basin, these reasons were common and already happening from the past, many centuries ago [7, 8].

The natural silt disposition, erosion, formation of various types of deltas, and shifting of shoal are not new for this basin. But in the past few decades, a sudden rise in silt disposition has been encountered in the basin, and thousands of natural drainages have become paleochannels due to sedimentation [9, 10]. River Ganga along with six other major rivers i.e., Gandak, Budhi Gandak, Bagmati, Kamla Balan, Kosi, and Mahanada flows towards the Himalayan foothills and confluence into Bay of Bengal which is situated downstream part of the river Ganga near the Indian ocean. The shoal formation can be easily seen in river flow areas. The continuous formation of shoal in the river has reduced the flow area and during the monsoon, it inundates millions of hectares of agricultural land every year in Bihar [11]. Which is a source of income for the farmers living in these areas [12]. The impact of flooding is severe in this region which reals many human life, it also deteriorates various structures such as embankments, channels, etc [13]. Apart from that, a few more reasons for flooding need to be diagnosed for better prevention of flooding especially for project and policy development [14]. Recently, the government of Bihar has shown concern in this matter for an in-depth study of the problem, including economic losses and its possible solutions [15]. It also emphasizes the estimation of the long-term environmental problem due to various engineering projects made on the Ganga River basin [16]. For this purpose, a study has been conducted using various tools & techniques such as field survey data, satellite imageries, modeling approaches, etc.

The Landsat and Sentinel data products were mostly used in this study. Satellite imageries have been available from the year 1972 to recent days [17]. The satellite imageries were further used to estimate the sediment deposit areas in the form of shoals. The shoal area formation in the river has been extracted from the post-flood season mostly from September to November months for every year [18, 19]. The digitization method has been used for the extraction of the information. The method is widely used for accurate estimation of the features as compared to various other methods [20]. Further, the digitization of all the drainage networks has been done for the basin. The steps were essential to assess the drainage condition in different catchments. The drainage networks were further classified into active, semi-active, and dead drainage networks. The different classes identified in the study were useful in planning & implementing work for various agencies working in this field [21]. In this study, HEC-RAS modeling has also been done to identify the flow pattern using the hydrodynamic velocity vector pattern. The steps were useful in the identification of blocked or encroached drainage networks in the study area. The information obtained by the modeling was further used for the validation using field datasets [22]. The methodology is very simple and effective for river, drainage, and other related rejuvenation projects in several parts of the world [23-26].

Study Area Map

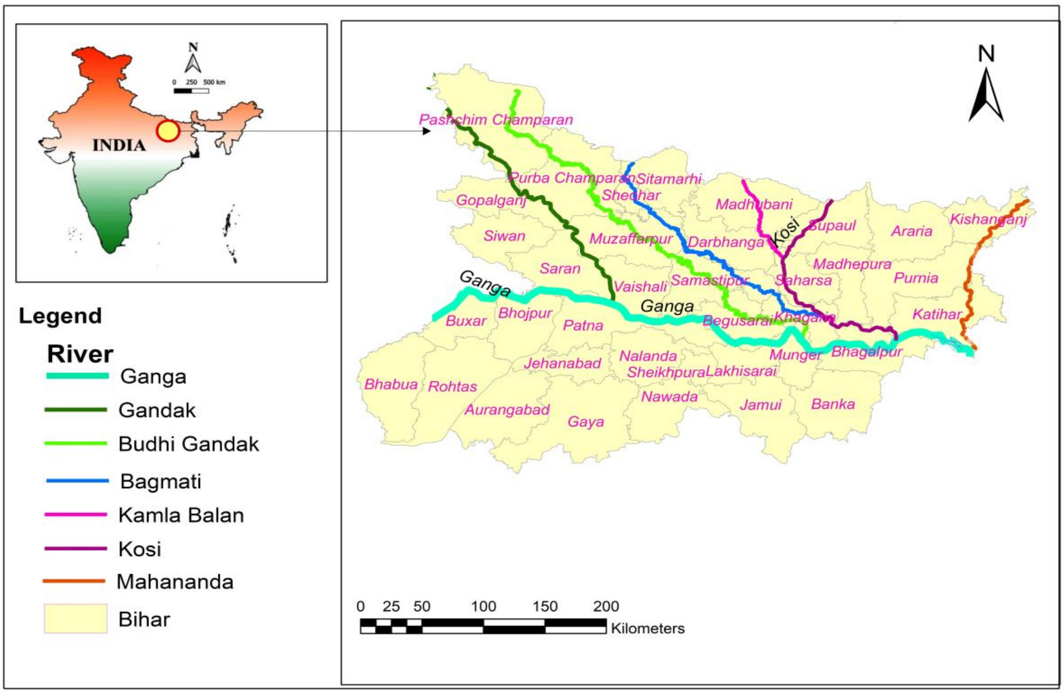

Figure 1: Study Area Map Showing North and South Bihar

The study area is situated in the Bihar state of India. The river Ganga divides the states into two halves, i.e., North and South Bihar. North Bihar is one of the most densely populated areas in India. The study area is situated at the foothills of the Himalayas, and it is also the origin of more than two hundred perennial rivers that flow across several districts and get confluences in various tributaries of the River Ganga. The average annual rainfall is about 1100 mm. Almost every year the flood hits this part of the state and inundates approximately twenty-one districts in monsoon season. The study area is highly suitable for the maize, banana, and wheat crops, which are low water-tolerant species, and every year, these crops are affected due to flood waterlogging. The floodwater stands for more than three months in most places, and it highly affects the horticulture crops.

Methodology

Methodology Flow Chart

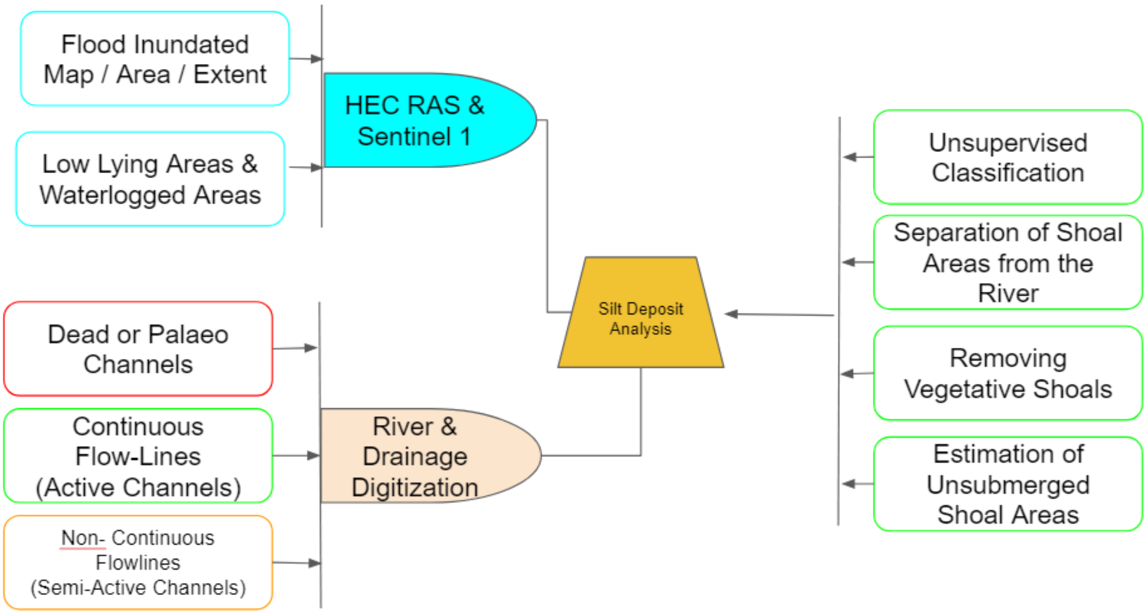

Figure 2: Methodology Flowchart of the Study

The aim of the study was to identify the reasons of siltation in various river systems including listing of degraded channels. The entire methodology has been categorised into four different segments i.e. modelling and mapping of flood inundation areas, separation of channels types, mapping of sediment deposit locations, calculation of sediment areas, The details procedure are listed below.

Separation of Channels Types: The three classifications i.e. active, blocked, and dead channels help in identification of channels and its condition i.e. useful in decision making for it de-siltation, restoration, excavation or other activities needed to maintain the ecological flow in the channels. The details of the channels are explained below.

Active Channels: In the active channels the continuous flow of water takes place from upstream to downstream. In the study areas, the rivers are perennial and flowing after glacier melt. These channels are free from obstacles and allow the water to pass from the channels.

Blocked Channels: The blocked channels are chocked at several locations in its flow area. The blockage may be from various reasons such as sediment accumulation, debris, agricultural practices, natural weeds, etc. The blockage restricts the flow of water in the channel. It is required to de-sediment the channels regularly to maintain the flow.

Dead Channels: The channel is completely dead or paleo channels. The channels have only bank lines with a minor elevation over the ground but they can be identified by using satellite imageries.

Active Channels | Semi Active or Blocked Channels | Dead Channels

Figure 3: River Channels and its Flow Types

Mapping of Sediment Deposit Locations (Shoal) in River Flow Areas: Rock weathering and sediment transportation is a natural process. This phenomenon is continuously happening for millions of years. The sediments deposited over the floodplain areas create alluvial lands, and it is highly suitable for agriculture practices, but sedimentation in river or drainage networks creates a hindrance to the river flow. It is necessary to de-sediment the river at regular intervals. The manual identification of the sedimentation sites is a difficult task for researchers and other agencies working in this field. In this context, the use of optical and microwave satellite imagery plays an important role in shoal area mapping. In this study, the mapping of the shoal area for all six major rivers of North Bihar has been done from the period of 1972 to 2022.

Sedimentation in River Kamla Balan | Sediment area estimation of the Kamla Balan River

Figure 4: Shoal Area Mapping Using Satellite Imageries

Sediment Area Calculation: River degradation is a serious issue for various river ecosystems in the world. It happens due to various anthropogenic and natural activities such as the construction of dams, reservoirs, barriers, etc. Reducing the river or drainage velocity by any means is responsible for river degradation by the accumulation of sediment particles in the channels. Slowly, and continuous process in the river areas creates a large volume of sediment deposition. During the lean period, the sediment area is visible. The satellite imagery is highly useful in identification and estimate of these areas. In this study, the estimation of sediment areas has been by using digitization techniques from the year 1972 to 2022.

Identification of Waterlogged & Flood Affected Areas: In this study, the identification of highly silted drainages or paleo-channels was also verified using flood inundation & waterlogged maps prepared by MODIS NRT and Sentinel 1 data products. These layers are already available on the Dartmouth Flood Observatory site. It needs to extract the information from there. The link to the site is https://floodobservatory.colorado.edu/. For the validation of the data a breach model was developed in HEC-RAS Model for Kosi river. The model output was used to match the water extent during flood.

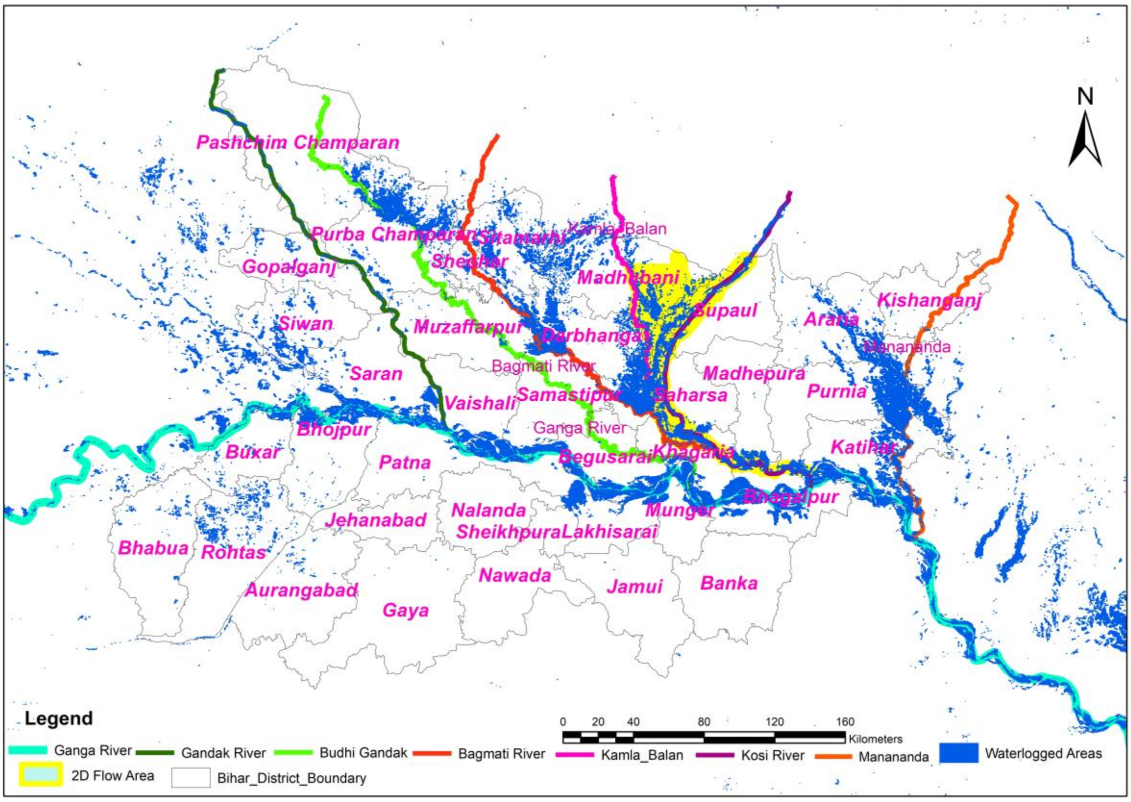

Figure 5: Flood Inundation & Waterlogged Area Map Obtained from Dartmouth Flood Observability (DFO)

Result

The overall research of the study was to identify the rate of sediment deposit in the Ganga River basin along with its locations, identification of various types of drainage systems, separation of endangered drainage networks, validation of waterlogged data using HEC-RAS breach model output. The result obtained by the study has been divided into two segments. The first part is the rate of sedimentation and its areas in various rivers in the Ganga Basin, the second is drainage categorization. All the pieces of information obtained in this study are highly relevant to understand the long-term river degradation study, river rejuvenation, and other related works. The details of the findings are described below.

Sedimentation in Gandak River: The sediment accumulation in the river is responsible for the blockage of the river & drainage system. The sediment accumulation in the rivers Gandak, Bagmati, Budhi Gandak, Kamla Balan, Kosi, and Mahananda was mapped in this study. The first river mapped in the study was River Gandak. The river originates from Tibet. This river is also known as the Kali and Narayani Rivers. The total length of the river is 631 Km. In which 446 lies in India and approximately 305 Kilometres flows in Bihar state. The detailed sediment accumulation area within the flow area is listed in the Table 1.

Year	Gandak	Year	Gandak	Year	Gandak
1972	6.03	1989	84.66	2006	162.63
1973	5.97	1990	94.17	2007	132.39
1974	11.23	1991	76.62	2008	123.59
1975	31.64	1992	60.68	2009	123.30
1976	34.30	1993	88.27	2010	197.98
1977	20.23	1994	57.35	2011	159.86
1978	17.25	1995	66.99	2012	160.66
1979	18.44	1996	86.76	2013	301.60
1980	17.93	1997	251.83	2014	305.55
1981	16.22	1998	196.30	2015	160.66
1982	18.99	1999	130.82	2016	112.80
1983	36.77	2000	272.37	2017	190.33
1984	41.44	2001	108.86	2018	120.33
1985	52.44	2002	211.00	2019	117.20

1986	55.33	2003	260.11	2020	109.07
1987	45.55	2004	262.65	2021	124.25
1988	70.48	2005	86.36	2022	150.23

Table 1: Sedimentation Detail of Gandak River

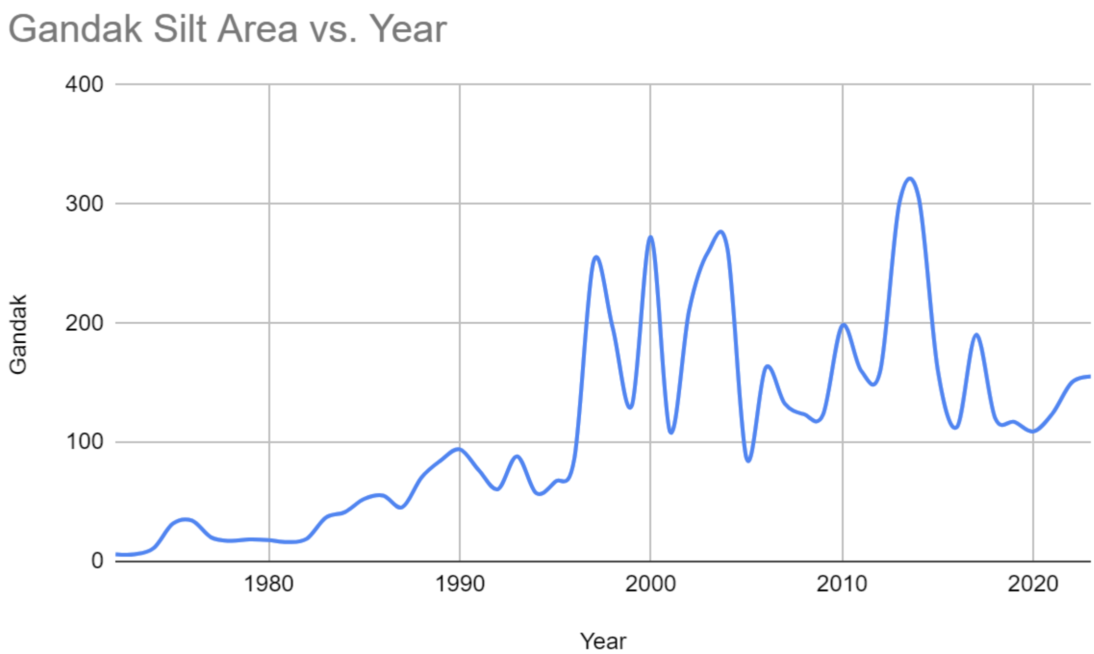

Figure 6: Sedimentation detail of River Gandak from the Year 1972 to 2022

(Fig. 06) indicates that the sedimentation in the river area was very low, i.e., below five square Kilometres, during the year ninety seventy-two. It starts rising around ninety-eighty-two to ninety-ninety-five, and a sudden rise in the sedimentation area happens around ninety-ninety-six onwards. It continuously starts rising, and the silted area rises around two hundred seventy Sq. Km. The sediment area exceeded more than three hundred square Kilometres around the year two thousand fifteen, and the sediment area decreased to some extent, and now it again started rising.

Sedimentation in Budhi Gandak River: The Budhi Gandak originates from the Chautarwa Chaur land in the West Champaran district of Bihar. The total length of the river is about 320 Km. The river is perennial and sub-surface flow is dominant in the river. During the analysis, it was found that the sediment accumulation in the Budhi Gandak River has been rising from the year 1980 to 2022. The sedimentation causes the flooding and inundation of agricultural lands. The detail of the sedimentation areas is listed in Table 2.

Year	Budhi Gandhak	Year	Budhi Gandhak	Year	Budhi Gandhak
1972	7.02	1989	187.63	2006	28.27
1973	6.12	1990	153.25	2007	116.92
1974	6.11	1991	128.25	2008	68.68
1975	12.73	1992	97.88	2009	79.78
1976	11.25	1993	95.25	2010	99.24
1977	27.28	1994	89.23	2011	135.99
1978	54.21	1995	95.25	2012	147.02
1979	45.23	1996	101.23	2013	149.88
1980	60.22	1997	117.58	2014	121.34
1981	78.56	1998	130.16	2015	91.77
1982	33.27	1999	101.61	2016	126.49
1983	89.65	2000	78.99	2017	131.27
1984	90.65	2001	61.21	2018	130.22
1985	105.25	2002	76.67	2019	139.00
1986	107.25	2003	22.12	2020	135.95

1987	190.45	2004	41.41	2021	132.01
1988	221.29	2005	7.86	2022	132.01

Table 2: Sedimentation Detail of the River Budhi Gandak

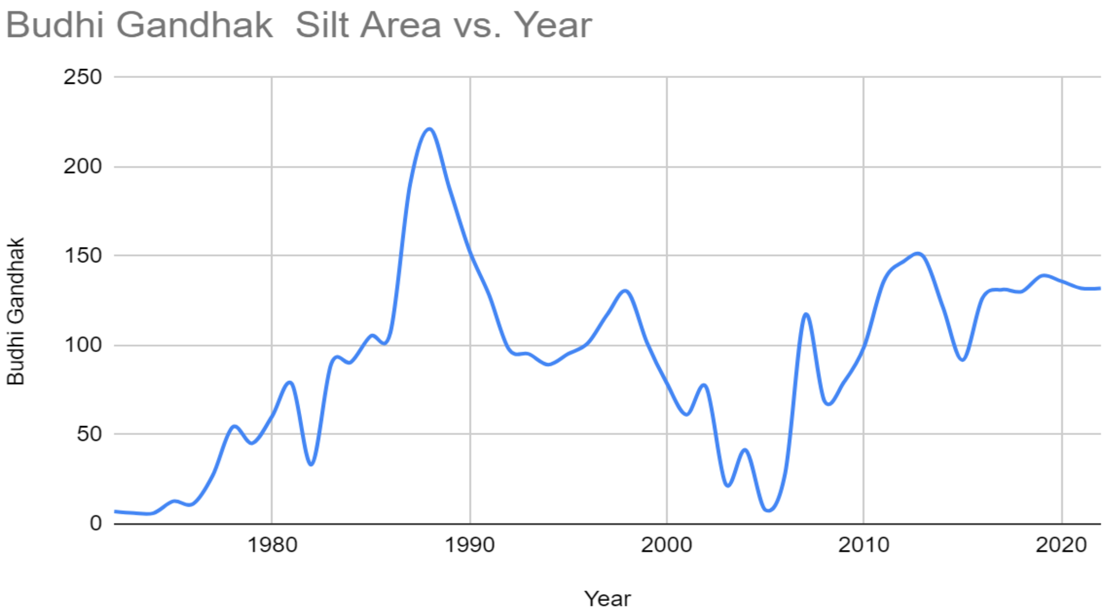

Figure 7: Sedimentation Details of River Budhi Gandhak from the Year 1972 to 2022

The sedimentation in river Budhi Gandak has been explained in (Fig. 07). in this graph it is indicated that the sediment deposit was much less around one to two square Kilometres in starting of the year i.e. ninety seventy-two. It gradually starts rising to around nineteen eighty-five. The sediment deposit falls after a few years up to two thousand five and again it is rising these days.

Sedimentation in Bagmati River: The Bagmati river originates from Baghdwar Falls in Nepal and flows through various hills and valleys in Kathmandu. The river enters India at Bairgania town in Sitamadhi district. The total length of the river is 587 Km. The river flows from the various districts of North Bihar. This river also encountered sedimentation in the past couple of decades. The sedimentation has risen during the period 1995 to 2000. The detail of the sediment deposition is listed in Table 03.

Year	Bagmati	Year	Bagmati	Year	Bagmati
1972	4.44	1989	8.25	2006	91.95
1973	3.45	1990	12.95	2007	14.29
1974	10.25	1991	85.76	2008	115.00
1975	14.25	1992	87.86	2009	32.48
1976	5.27	1993	89.25	2010	70.32
1977	11.25	1994	64.43	2011	89.56
1978	23.11	1995	96.44	2012	95.25
1979	45.25	1996	91.33	2013	105.25
1980	32.22	1997	14.03	2014	147.49
1981	35.22	1998	181.23	2015	122.79
1982	40.56	1999	150.25	2016	124.22
1983	60.12	2000	139.16	2017	125.02
1984	45.22	2001	52.25	2018	111.25
1985	70.25	2002	125.00	2019	128.64
1986	77.25	2003	127.28	2020	210.55
1987	87.72	2004	82.45	2021	136.00
1988	6.68	2005	125.27	2021	140.22

Table 3: Sedimentation Detail of the River Bagmati

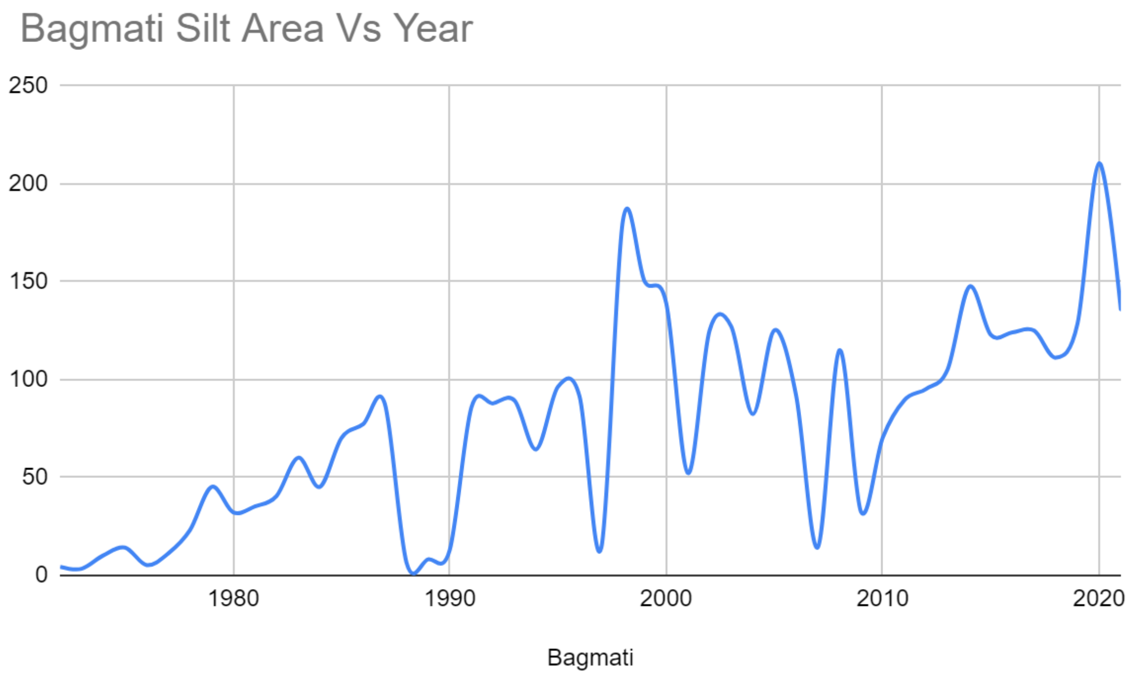

Figure 8: Sedimentation Detail of the River Bagmati from the Year 1972 to 2022

The rise in sediment deposits in the Bagmati River area can be seen in this (Fig. 08). In nineteen seventy-two the sediment deposit area was below fifty square Kilometres and it was rising from the year ninety-eighty to ninety-eighty-seven. In the year ninety-ninety-six, the sediment area exceeded near about two hundred square Kilometres and it is gradually rising these days.

Sedimentation in Kamla Balan River: The river originates from the Sindhauli District of Nepal. It enters in Madhubani district of Bihar, India. The total length of the river is 328 Km. The river gets confluence in the Bagmati River near Badalghat in the Khagaria districts. In this study, it has been found that the river sedimentation was continuously rising but the sudden rise between the year 2010 to 2015 has been reported in the flow-path of the river. The details of the sedimentation of the Kamla Balan River is listed in the Table 04.

Year	Kamla Balan	Year	Kamla Balan	Year	Kamla Balan
1972	3.71	1989	10.99	2006	2.31
1973	3.069	1990	9.01	2007	6.11
1974	3.55	1991	7.59	2008	4.94
1975	5.74	1992	6.408	2009	5.04
1976	6.48	1993	8.45	2010	5.82
1977	5.20	1994	5.39	2011	4.38
1978	5.66	1995	4.20	2012	38.16
1979	2.95	1996	6.33	2013	38.25
1980	4.28	1997	7.18	2014	5.07
1981	6.22	1998	6.21	2015	5.45
1982	4.45	1999	11.23	2016	3.70
1983	11.25	2000	14.25	2017	4.28
1984	8.25	2001	7.45	2018	16.25
1985	7.25	2002	7.25	2019	10.01
1986	4.21	2003	5.26	2020	51.29
1987	6.80	2004	5.00	2021	61.45
1988	4.13	2005	6.57	2022	55.02

Table 4: Sedimentation Details of the River Kamla Balan

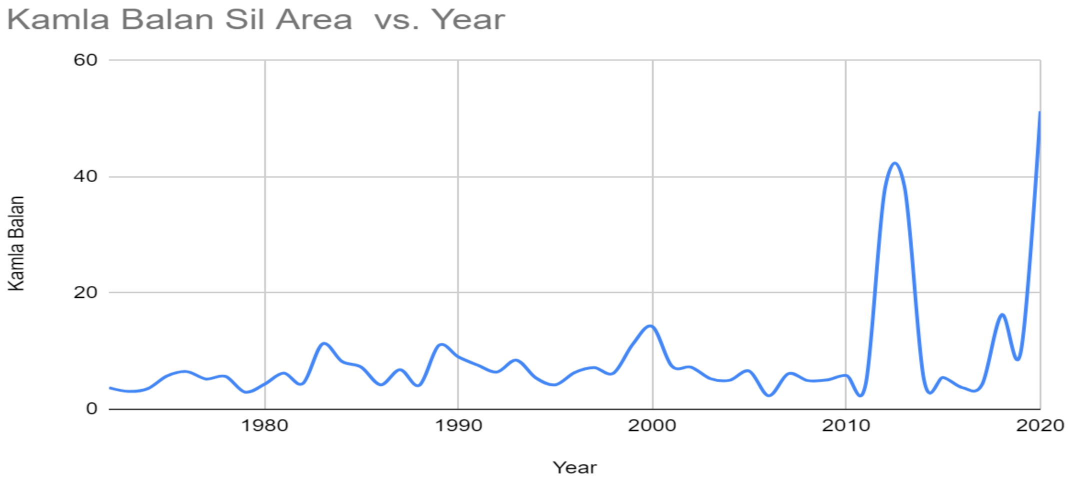

Figure 9: Sedimentation Detail of the River Kamla Balan from the Year 1972 to 2022

The Kamla Balan River has very low sediment deposition but during the period two thousand ten the sediment area rises and the reduction in sediment area occurred up to a thousand in 2018. The recent data indicates that it is rising.

Sedimentation in Kosi River: Kosi River originates in the Himalayan range of Tibat & Nepal adjoining three tributaries i.e. Sun, Tamur, and Arjun Kosi. The river has a wide history of breading channels. The total length of the Kosi River is 729 Km. In this research, it has been found that the sedimentation in the river is continuously risen from the year 1980 to 2022 and suddenly the sediment area has been decreased between the year 1998- 2000. The detail of the sedimentation of the Kosi River is listed in the Table 05.

Year	Kosi	Year	Kosi	Year	Kosi
1972	41.92	1989	223.96	2006	226.95
1973	45.25	1990	147.89	2007	156.73
1974	64.55	1991	205.51	2008	225.25
1975	74.99	1992	265.61	2009	202.41
1976	71.43	1993	200.56	2010	64.63
1977	89.25	1994	186.77	2011	100.82
1978	26.95	1995	198.25	2012	96.48
1979	72.33	1996	221.06	2013	99.23
1980	47.84	1997	229.03	2014	102.12
1981	80.25	1998	116.95	2015	149.63
1982	87.25	1999	145.25	2016	91.93
1983	102.35	2000	53.341	2017	102.04
1984	107.45	2001	121.58	2018	150.23
1985	142.03	2002	115.58	2019	223.35
1986	156.02	2003	101.84	2020	102.65
1987	171.90	2004	276.39	2021	94.96
1988	163.48	2005	208.30	2022	125.25

Table 5: Sedimentation Detail of River Kosi

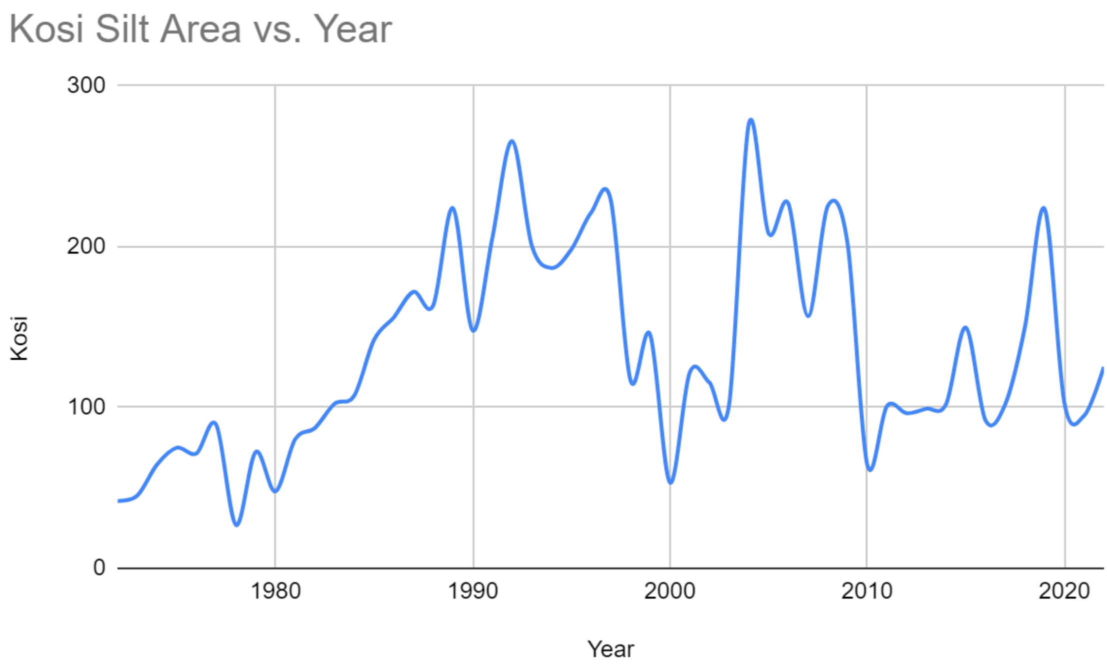

Figure 10: Sedimentation Detail of the River Kosi from the Year 1972 to 2022

The Kosi River always changes its flow path due to heavy sedimentation and submersed the area nearby. In the (Fig. 10). It is clear that the sediment deposition was less before nineteen eighty and it was around a hundred square Kilometres. After ninety eighty it rises and reaches around three hundred square Kilometres and gradually it is rising.

Sedimentation in Mahananda River: The river originates from the Himalayan Range and confluence with River Ganga at Godagari Ghat in Bangladesh. The total length of the river is 360 Km. During the study, it was found that the river has been silted continuously since 1975. It is also one of the most degraded rivers among all other rivers selected for this study. The sediment area exceeded more than four hundred Square Kilometres in its confined flow area. The detail of the sedimentation is listed in the Table 6.

Year	Mahananda	Year	Mahananda	Year	Mahananda
1972	46.77	1989	356.89	2006	257.96
1973	53.49	1990	349.38	2007	212.79
1974	54.22	1991	442.01	2008	251.13
1975	87.95	1992	427.07	2009	312.83
1976	85.23	1993	405.23	2010	300.05
1977	70.95	1994	250.65	2011	252.96
1978	98.23	1995	432.22	2012	307.25
1979	202.20	1996	376.13	2013	293.51
1980	301.35	1997	372.60	2014	293.51
1981	250.23	1998	391.22	2015	239.47
1982	245.25	1999	391.22	2016	269.55
1983	302.01	2000	292.31	2017	226.60
1984	307.01	2001	285.30	2018	303.25
1985	350.12	2002	352.54	2019	260.28
1986	378.22	2003	299.92	2020	166.59
1987	357.23	2004	260.22	2021	299.41
1988	378.01	2005	273.75	2022	302.22

Table 6: Sedimentation Details of the River Mahananda

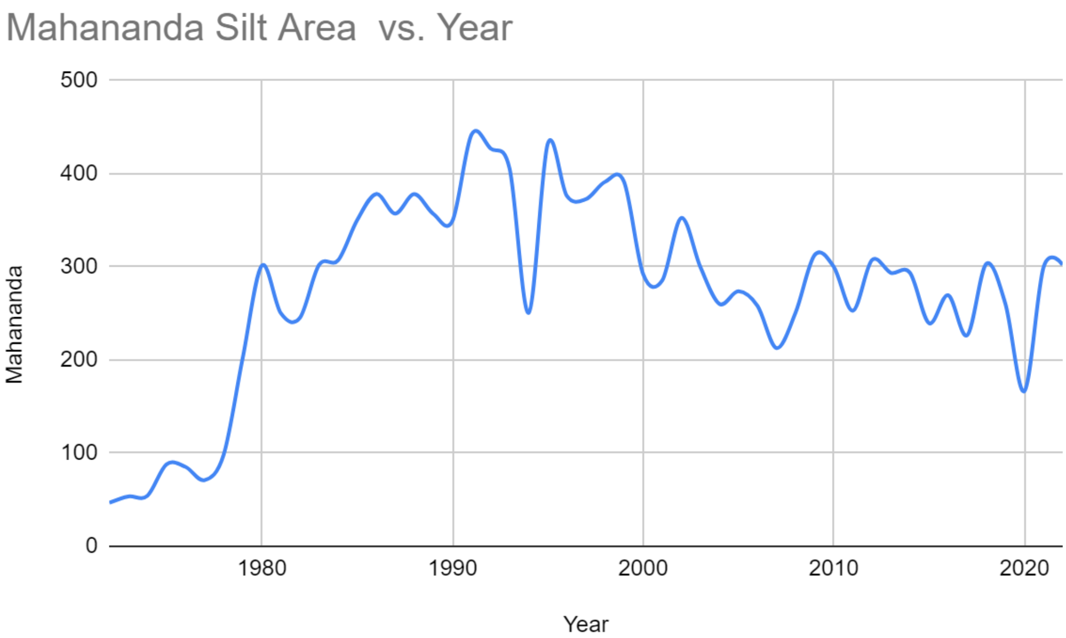

Figure 11: Sedimentation Detail of the River Mahananda from the Year 1972 to 2022

The sediment deposition rate in the year nineteen seventy-two to nineteen seventy-eight was very low and it was below a hundred square Kilometres but gradually it rises and reached around three hundred Square Kilometres in ninety eighty. The rate of sediment deposition continuously rises in the Mahananda river area and at present it is around three hundred square Kilometres.

Drainage Categorization

Drainage categorization It refers to the various types of available drainage networks in study areas. These drainage categories help in deciding the types of drainages according to their physical properties. It also helps in the planning and implementation of various maintenance works. In this study, a total of three categories have been made according to the implementation of works i.e. active, semi-blocked, and active drainages. These three categories are helpful in the river and drainage rejuvenation works for flood and disaster management. The details of the drainage are listed in Table 7. and (Fig.12). The blue colour in the map indicates the active channels while the yellow colour indicates the semi-blocked channels and the red colour represents the completely blocked or dead channels.

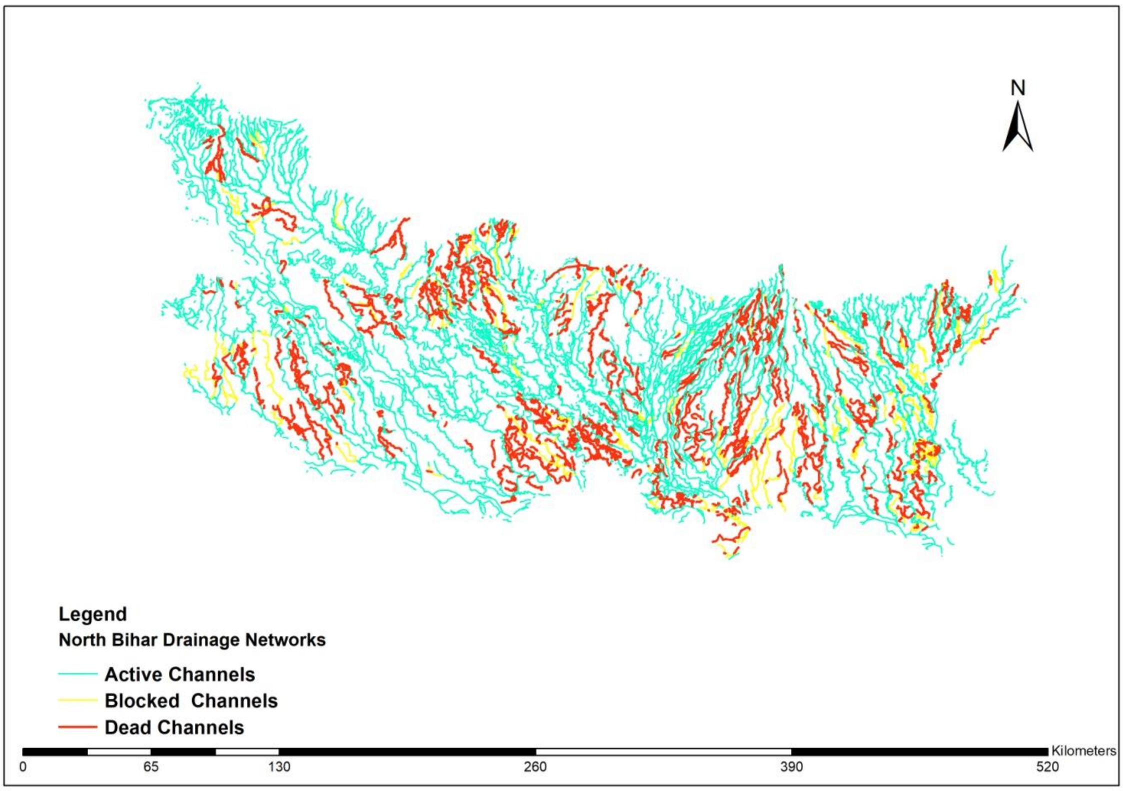

Figure 12: North Bihar River and Drainage Details

Sr. No	Drain Types	Count	Length in Km.	Percentage
1.	Active Drainages	9159	24051.73	74.03
2.	Semi Active Drainages	279	2278.81	7.014112
3.	Block or Dead Drainages	796	6158.39	18.95535

Table 7: Drainage Detail and its Types

Conclusion

The present study indicates that a high sediment deposit occurred from 1972 to the 2022 in the Ganga Basin. The sediment deposit is one of the major causes of flooding. Sediment deposition is a natural process, and the channels need to be managed or de-sedimented over some time. The methodology developed in the study is highly capable of identifying paleo-channels and semi-active channels. The tools are also useful in planning and implementing river and drainage rejuvenation projects.

Acknowledgment

The authors express their gratitude to the team Applied Remote Sensing Training ARSET (NASA) for providing hands-on training on the application of various remote sensing tools and datasets in the field of water management. The authors also thank the German Development Cooperation Team (GIZ) India and Bihar Rural Development Society (BRDS) Patna for providing the basic facilities and guidance to achieve the goal.

References

1. Braemer, F., Geyer, B., Castel, C., & Abdulkarim, M. (2010). Conquest of new lands and water systems in the western Fertile Crescent (Central and Southern Syria). *Water History, 2*, 91-114.
2. Scarborough, V. L., & Lucero, L. J. (2010). The non-hierarchical development of complexity in the semitropics: Water and cooperation. *Water History, 2,* 185-205.
3. Mitra, R., Chakrabarti, G., & Shome, D. (2020). Sedimentation history and depositional model of palaeo-mesoproterozoic tadpatri formation, Cuddapah basin, India. *Journal of Sedimentary Environments, 5,* 87-100.
4. Rahman, M. M., Hasan, M. F., Hasan, A. M., Alam, M. S., Biswas, P. K., & Zaman, M. N. (2021). Chemical weathering, provenance, and tectonic setting inferred from recently deposited sediments of Dharla River, Bangladesh. *Journal of Sedimentary Environments, 6*, 73-91.
5. Afradi, A., Alavi, I., & Moslemi, M. (2021). Selecting the best mining method using analytical and numerical methods. *Journal of Sedimentary Environments, 6*(3), 403-415.
6. Ngwakfu, N. S., Eric, B. E., Betrant, B. S., Fralick, P., Fidelis, M. E., & Agyingi, C. M. (2024). Geochemistry of sand along the coastal beaches of the Mundeck formation and River Ntem, south Cameroon. *Journal of Sedimentary Environments, 9*(3), 561-579.
7. Sababa, E., Ekoa Bessa, A. Z., Aye, B. A., Loubahndem, A. S. B., & Welba, M. (2023). Alluvial sediments in Bol area (Lake Chad Basin): implications for source area-weathering and tectonic settings. *Journal of Sedimentary Environments, 8*(4), 563-586.
8. Alem, B. B., Wosenie, M. D., & Tilahun, S. A. (2022). Runoff and suspended sediment yield and implications for watershed management. *Journal of Sedimentary Environments, 7*(2), 199-210.
9. Kumar, N., Lal, D., Sherring, A., & Issac, R. K. (2017). Applicability of HEC-RAS & GFMS tool for 1D water surface elevation/flood modeling of the river: a Case Study of River Yamuna at Allahabad (Sangam), India. *Modeling Earth Systems and Environment, 3*(4), 1463-1475.
10. Kumar, N., Kumar, M., Sherring, A., Suryavanshi, S., Ahmad, A., & Lal, D. (2020). Applicability of HEC-RAS 2D and GFMS for flood extent mapping: a case study of Sangam area, Prayagraj, India. *Modeling Earth Systems and Environment, 6*(1), 397-405.
11. Kermani, S., & Boutiba, M. (2023). Grain-size analysis and quartz surface microtextures observations of sediments from Jijelian East coast, Algeria: sedimentary environment implications. *Journal of Sedimentary Environments, 8*(2), 193-208.
12. Boboye, O. A., Jaiyeoba, O. K., & Okon, E. E. (2021). Sedimentological characteristics and mineralogical studies of some Cretaceous sandstones in Nigeria: Implications for depositional environment and provenance. *Journal of Sedimentary Environments, 6*(4), 531-550.
13. Wester, P. (2009). Capturing the waters: the hydraulic mission in the Lerma–Chapala Basin, Mexico (1876–1976). *Water History, 1*, 9-29.
14. Crowell, J. K., & Hembree, D. I. (2023). Climate-induced changes in fluvial ichnofossil assemblages of the Pennsylvanian–Permian Appalachian Basin. *Journal of Sedimentary Environments, 8*(2), 261-282.
15. Foreman, B. Z., Maxbauer, D. P., Lesko, A. K., Erhardt, A. M., Rasmussen, D. M., & Lalor, E. F. (2022). Floodplain evolution during the early Paleogene within the Piceance Creek Basin, northwest Colorado, USA. *Journal of Sedimentary Environments, 7*(4), 711-744.
16. Dile, Y. T., & Srinivasan, R. (2014). Evaluation of CFSR climate data for hydrologic prediction in data-scarce watersheds: an application in the Blue Nile River Basin. *JAWRA Journal of the American Water Resources Association, 50*(5), 1226-1241.

17. Jana, S. (2022). Short-term estimation of beach sedimentation pattern in the mixed-energy environment at Digha coast, India. *Journal of Sedimentary Environments, 7*(1), 1-19.
18. Wilkinson, T. J., & Rayne, L. (2010). Hydraulic landscapes and imperial power in the Near East. *Water History, 2*, 115-144.
19. Ertsen, M. W. (2010). Structuring properties of irrigation systems: understanding relations between humans and hydraulics through modeling. *Water History, 2*(2), 165-183.
20. Anand, A., Beg, M., & Kumar, N. (2021). Experimental studies and analysis on mobilization of the cohesionless sediments through alluvial channel: a review. *Civil Engineering Journal, 7*(5), 915-936.
21. Lawmchullova, I., & Rao, C. U. B. (2024). Estimation of siltation in Tuirial dam: a spatio-temporal analysis using GIS technique and bathymetry survey. *Journal of Sedimentary Environments, 9*(1), 81-97.
22. Verma, M., Kanhaiya, S., Singh, B. P., & Singh, S. (2022). Signatures of provenance, tectonics and chemical weathering in the Tawi River sediments of the western Himalayan Foreland, India. *Journal of Sedimentary Environments, 7*(3), 425-441.
23. Lound, S. P., Birch, G. F., & Dragovich, D. (2022). Estimation of bedload sedimentation rate in a paleo-drowned river-valley. *Journal of Sedimentary Environments, 7*(4), 633-650.
24. Fuka, D. R., Walter, M. T., MacAlister, C., Degaetano, A. T., Steenhuis, T. S., & Easton, Z. M. (2014). Using the Climate Forecast System Reanalysis as weather input data for watershed models. *Hydrological Processes, 28*(22), 5613-5623.
25. Awais, M. (2023). Sediments/rocks color and Munsell Soil Color chart (a color tool for sedimentologists). *Journal of Sedimentary Environments, 8*(2), 137-138.
26. Chauhan, D. S., Chauhan, R., & Singh, B. (2022). Provenance composition, paleo-weathering and tectonic setting of Himalayan foreland basin sediments, Kumaun Sub-Himalaya, India. *Journal of Sedimentary environments, 7*(3), 471-499.