GANGA of the Past

MoWR, RD&GR
Government of India

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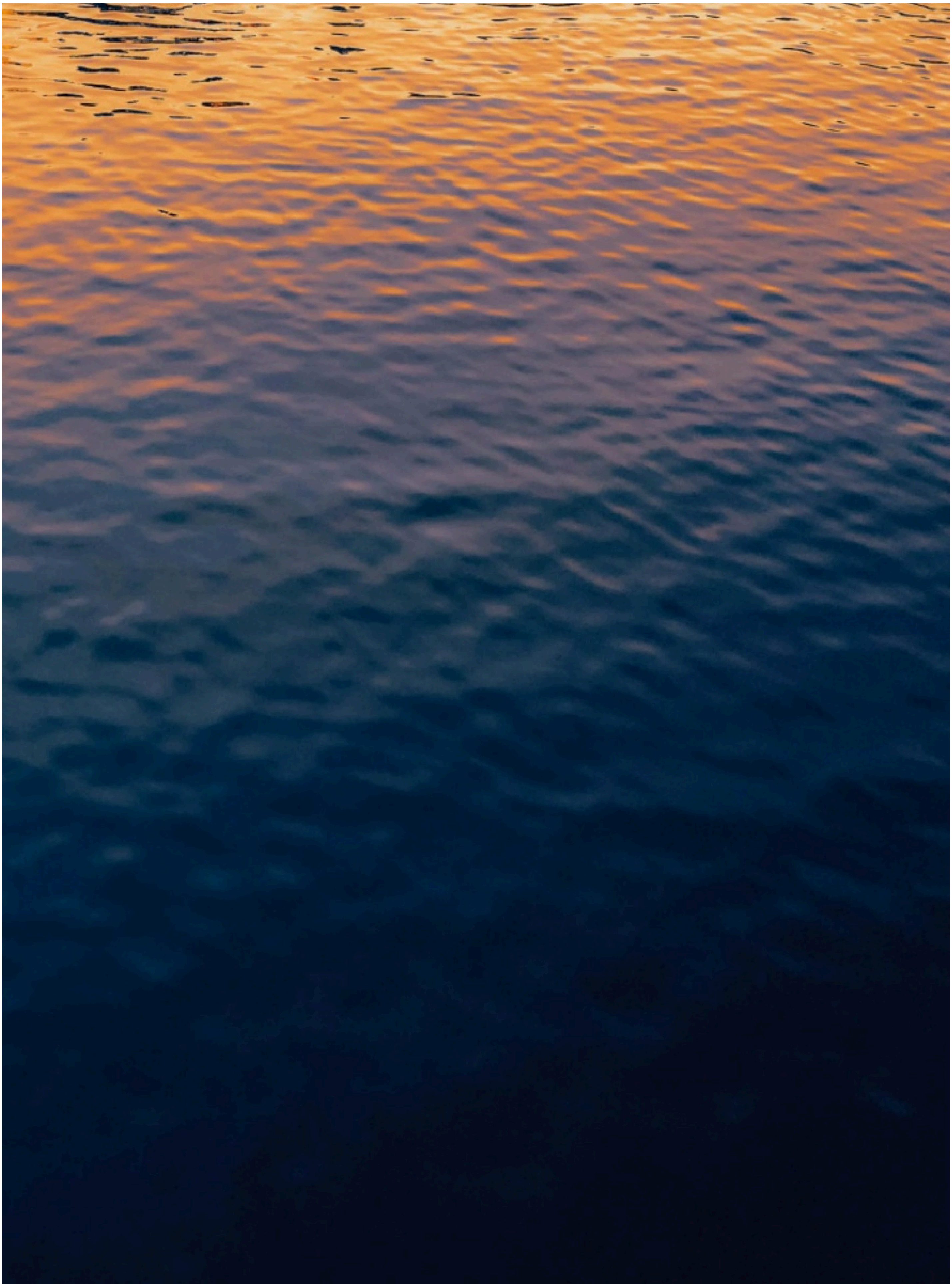

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गजेन्द्र सिंह शेखावत
Gajendra Singh Shekhawat

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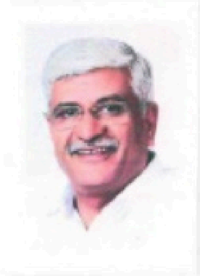

22 OCT 2021

Message

Rivers have always been the lifeline of civilization in ancient as well in modern times. The River Ganga has a particularly important place in India in terms of supporting a large population for water resources, livelihood, and socio-cultural sustenance. The riverine ecology of the Ganga is simply unique, and it supports a rich biodiversity in its 2500 km length. Increasing population pressure and water demands have posed a threat to this important river. The Ministry of Jal Shakti, Government of India is committed to restore the glory of the Ganga.

This effort of the National Mission for Clean Ganga (NMCG) and the Indian Institute of Technology, Kanpur (IIT-K) to reconstruct the Ganga of the past from Corona Archival Imagery and to come out with an Atlas of the "Ganga of the Past" is not only commendable but also aligns very strongly with the long-term perspective of the Hon'ble Prime Minister, Shri Narendra Modiji, to restore the past glory of the Ganga River.

The vivid images of the Ganga put together by the team of IIT Kanpur led by Professor Rajiv Sinha remind us of the geological as well as socio-cultural importance of this river in the Indian context. The associated information for each of the carefully selected areas along the Ganga will go a long way to educate the scientists as well as the common man of this country.

I wish a great success to this endeavor.

(Gajendra Singh Shekhawat)

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भारत सरकार
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MINISTER OF STATE FOR
JAL SHAKTI & TRIBAL AFFAIRS
GOVERNMENT OF INDIA
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MESSAGE

I would like to congratulate National Mission for Clean Ganga (NMCG) for funding a research project on "Reconstructing the Ganga of the past from Corona Archival Imagery" and the Indian Institute of Technology, Kanpur (IIT-K) for developing this Atlas on the "Ganga of the Past" under the project.

It is a wonderful initiative to go deep into the past of this majestic river using modern technology such as satellite image and to visualize how the river has evolved through time. It is particularly striking to see the remarkable changes in river form and its surroundings, in response to both natural as well as anthropogenic factors. The associated statistics presented in the Atlas make this effort even more valuable to understand the quantum of changes be in the position of the river, its morphological parameters or the land use status. The organization of maps and data presented in this Atlas is excellent and I am very pleased with the quality of its production.

I am sure that this Atlas will go a long way to generate awareness about river protection and conservation amongst the scientific community and various sections of the society.

20/10/2021
(Bishweswar Tudu)

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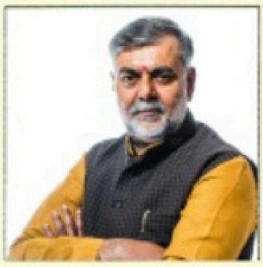
भारत सरकार
**MINISTER OF STATE FOR
FOOD PROCESSING INDUSTRIES
AND JAL SHAKTI
GOVERNMENT OF INDIA**

सत्यमेव जयते



MESSAGE

I am happy to note that the National Mission for Clean Ganga (NMCG) in collaboration with Indian Institute of Technology, Kanpur (IIT-K) have come out with this Atlas on the 'Ganga of the Past'. This Atlas brings out the significant diversity of the Ganga as it flows from the Himalayas and passes through the vast Gangetic plains and finally falls into the Ganga Sagar. During its long journey, this majestic river passes through several holy places such as Haridwar, Prayagraj and Varanasi and the documentation of the river in these windows is remarkable. The maps prepared from the historical satellite images and their explanation are very educative and should help the river managers to design site-specific strategies for management of the Ganga River. This Atlas is a good mix of scientific data, highlight of cultural heritage and an account of human-induced changes in the Ganga River around the major cities.

I complement the NMCG for funding the research project and IIT Kanpur for this stupendous effort.

(Prahlad Singh Patel)
21/10/21

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पंकज कुमार
PANKAJ KUMAR
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SECRETARY

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जल संसाधन, नदी विकास
और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

Message

Remote sensing technology has come a long way to visualize the Earth's landscape and its temporal evolution in different parts of the world. Satellite images have provided excellent datasets to examine changes in river form, whether natural or human-induced. I am happy to note that as a part of the research project funded by the National Mission for Clean Ganga (NMCG), the Indian Institute of Technology, Kanpur (IIT-K) took up this initiative of reconstructing the past changes of the Ganga, not only from a water resource perspective but also from a socio-cultural perspective impacting millions of people of this country. Visualizing the changes in river form, dynamics and land use changes in and around the river during the past couple of decades, through the graphics and images in this Atlas is educative and instructive. This Atlas is an excellent repository of information from a scientific as well as general perspective. It will go a long way to understand the transformation of the Ganga River over time, in response to human impact and facilitate designing sustainable management strategies.

I congratulate NMCG for supporting this initiative and IIT-K for executing this project so well. I look forward to wide circulation of this Atlas and feedback from the scientific community, river managers and social organisations committed to the betterment of river Ganga.

(Pankaj Kumar)

आज़ादी का अमृत महोत्सव

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राष्ट्रीय स्वच्छ गंगा मिशन
Rajiv Ranjan Mishra, IAS
DIRECTOR GENERAL
NATIONAL MISSION FOR CLEAN GANGA

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जल शक्ति मंत्रालय
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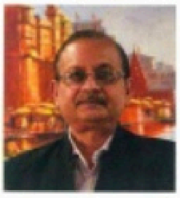
RIVER DEVELOPMENT & GANGA REJUVENATION



Message

One of the major tasks of the National Mission for Clean Ganga (NMCG) is to restore the Ganga, which originates in the mighty Himalaya and traverses through a large part of the country before draining into the Bay of Bengal, to its pristine glory. During its long journey through the Ganga plains, the river passes through a variety of geological settings and various places of significant cultural importance. During the last several decades, the river has gone through very significant changes driven by natural as well as human-induced factors and the NMCG is committed to identify the 'drivers' of these changes and to design sustainable mitigation measures. The Namami Gange program launched by NMCG in 2014 has emerged as one of the most important flagship programs of the Government of India which is aimed at rejuvenation of the National River Ganga in its totality.

In this context, we supported a pilot project to IIT Kanpur to document the changes in the Ganga River in a few selected windows using historical satellite images. The aim of the project was to reconstruct the Ganga of the past from Corona Archival Imagery. One of the most important datasets that have been used in this study is the Corona spy satellite data acquired by CIA, which have provided the images for the Ganga during 1960s, just before some of the major interventions were implemented along the river. These datasets remained classified for a long time but were released for the scientific community in middle 1990s. Combining these images with more recent images acquired by Landsat mission, Professor Rajiv Sinha and his team have produced a wonderful documentation of the geomorphic changes in several important stretches of the Ganga.

Some of the major highlights of this Atlas of the "Ganga of the Past" include the maps of historical changes in channel form and position, riverine environment and land use changes in and around the river. For each window, they have not only provided some interesting statistics of change but have also highlighted the socio-cultural and ecological importance. These datasets have been presented in a very lucid manner and should be easily understandable to the scientific community and the river enthusiasts alike. The NMCG would be happy to popularize this Atlas and ensure a wide circulation.

I congratulate the IIT Kanpur team for producing this admirable collection and I am sure that this will go a long way to serve the cause of restoring the holy Ganga.

(Rajiv Ranjan Mishra)

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Prologue

The Ganga basin in northern India is the most populous river basin in the world with nearly half a billion inhabitants. In the years that followed Indian independence in 1947, population expansion and human interventions have left the ecosystem of the Ganga in a severely damaged state with dwindling water levels polluted by human activity and natural sediment transport severely perturbed by dams and barrages. Fortunately, there is a growing recognition by the Ministry of Jal Shakti, the National Mission on Clean Ganga (NMCG) in particular, and several other organisations such as World Bank and the World Wildlife Fund (WWF) that the restoration of the Ganga to a healthier status, closer to its original unperturbed state, would set a strong foundation to future, greener, economic growth in Northern India. However, given the past six decades of fast development, efforts to restore the Ganga to its original condition are faced with a fundamental question: What was the original state of the Ganga? Answering this question will require some knowledge of the former course of the Ganga and of the farming and urban density of the surrounding plains before the impacts of human disturbance could be felt. Whilst challenging, this can be achieved, thanks to a unique dataset of declassified intelligence satellite photography. The Corona spy-satellite program collected a large number of earth observation photos in the 60s. These photos, now declassified, offer us a unique view of the Ganga at the very early stages of intense development and thus before the worst ecological damages occurred. However, these images are characterised by a lack of geographic reference and severe spatial distortions which render the raw product unsuitable for quantitative analysis.

This Atlas of the Ganga of the Past is an outcome of the project sanctioned to IIT Kanpur by the National Mission for Clean Ganga (NMCG), Ministry of Jal Shakti, Government of India to reconstruct the changes in the Ganga River through time in terms of its geomorphic condition. This Atlas attempts to walk through the different reaches of the Ganga and documents the geomorphic changes through time. We use images and graphics to convey simple messages and to integrate the river changes with the socio-cultural importance of the river at each site.

It is hoped that this Atlas will serve as a useful documentation to visualize the impacts on the Ganga River through time and to help initiate more comprehensive research and mitigation measures to arrest the decline of this majestic river.

Rajiv Sinha

Rajiv Sinha
Professor Department of Earth Sciences
IIT Kanpur

Devendra Pratap Mathuria
Executive Director (Technical)
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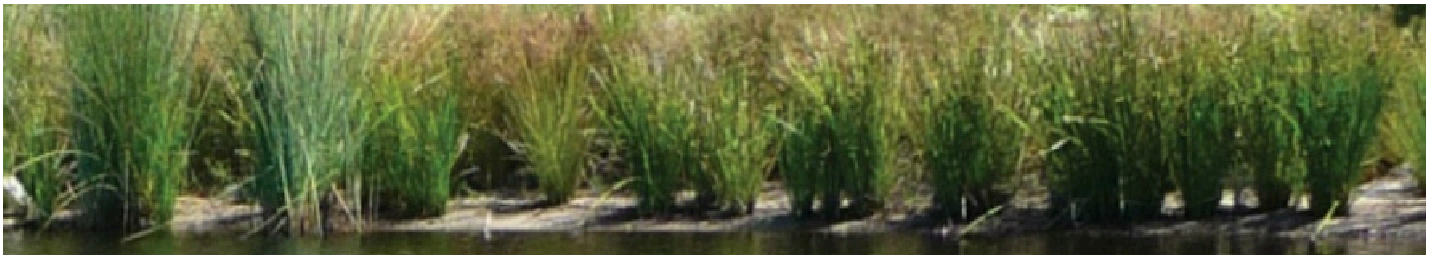
NAMAMI GANGE



Acknowledgements

We are grateful to the National Mission for Clean Ganga (NMCG), Ministry of Jal Shakti, Government of India for supporting this activity and for the encouragement throughout the execution of this very challenging project. The Director General of NMCG, Mr. Rajiv Ranjan Mishra, has been particularly supportive of this initiative and it is his keen interest and commitment to the cause of the Ganga which has led to the development of this Atlas. Mr. D.P. Mathuria and Mr. Peeyush Gupta at NMCG provided the unflinching support to this project in every possible way and we are grateful for their help. Continuous interactions with the ISRO team were extremely useful for improvising the methods and protocols with a view to make these accessible to professionals with minimal knowledge of remote sensing and GIS.

Mr. Smruti Ranjan Patra, a PhD student at the Department of Earth Sciences, IIT Kanpur worked tirelessly to generate all scientific data and products related to this project. He also worked on the development of protocols of geocorrecting the images, reconstructing geomorphic changes, and collecting basic information of each window. Another PhD student, Mr Dipro Sarkar, also helped in the initial stages of protocol development for geocorrection; in fact, he initiated this work much earlier during his master's thesis at IIT Kanpur which eventually led to the development of this project.

Mrs Shikha Sinha contributed significantly towards the overall design of the Atlas, perhaps the most painstaking part of this project. This work required several iterations to produce the most appropriate configuration of each page and we are grateful for her patience and hard work.

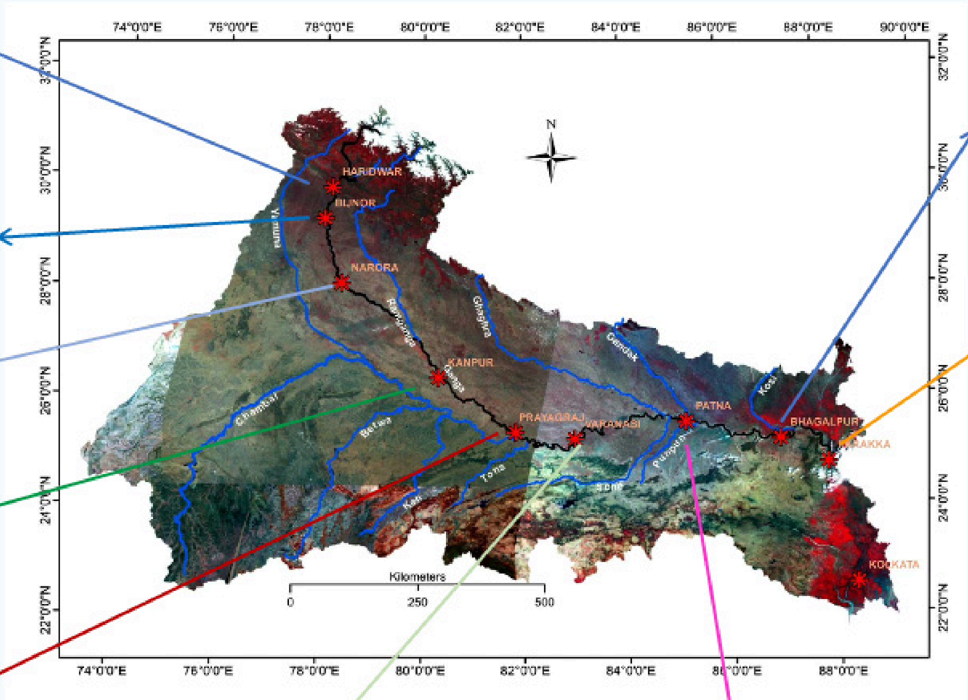
Background and Organization of the Atlas

Apart from natural forcings driven by hydrometeorological variabilities, the Ganga River has a long history of human impacts particularly in the last 4-5 decades. However, the most severe impacts began in the middle of the 20th century when the independent India began to intensify agriculture, hydropower development and industrial activity to support food security, energy security and economic development. In conjunction with rapid population growth and urban development, these multiple stressors have caused significant disturbances in flow regime, sediment transport and significant degradation of water quality. There is now a renewed interest in restoring this river basin which is home to nearly 7% of humanity (ca. 500 million inhabitants). Any such restoration effort will need to define an end-goal and establish a reference status which can be realistically achieved through restoration. Suitable geospatial data relating to the Ganga are somewhat difficult to obtain. While modern satellite imagery can now be used to infer a range of variables such as land-use, river geometry and even river discharge, the lack of availability and lower quality of satellite data for 1980s limits the usefulness of such approaches. Declassified imagery acquired as early as 1961 by the CIA and having resolutions from 1.8 to 7.5 meters offers the unique opportunity to extend the data window of civilian satellite imagery by two full decades. However, these images are characterised by a lack of geographic reference and severe spatial distortions which render the raw product unsuitable for quantitative analysis.

As a part of a research project funded by the NMCG, the IIT Kanpur has developed a workflow that allows users to process and analyse declassified imagery of riverine environments at minimal cost and using open source softwares. We demonstrate the use of corona imagery in establishing a reference condition and the use of modern remote sensing datasets to evaluate the land use land cover dynamics between the 1960s and recent time. The restoration of a heavily degraded large river such as the Ganga to a reasonable ecologic functionality is a challenging prospect. In order to have a clear goal, this process of restoration must be informed by some knowledge of a 'reference condition' i.e. the status of the river before the ecological damages. Ordinary maps are of limited usage since channel banks are approximate and no information on channel depth is available and seasonal effects (i.e. changes in the channel at high versus low water levels) are not represented. However, good quality aerial photography is in fact capable of delivering much of the needed information and of providing a good approximation of the reference condition. Unfortunately, aerial photographs are restricted to military uses in India. This leaves satellite imagery as the only source of data capable of giving scientists and managers a complete view of the entire Ganga. Since development began to accelerate in the 50s and 60s, data from Landsat-1, the first civilian imaging satellite launched in 1972 is too recent. However, the Corona images provide spatial resolutions below 10 meters which is competitive even by current standards. The Corona archive contains over 8000 images of the Ganga basin, declassified and provided to the public by the US Geological Survey. The technical details of geocorrection protocols of the Corona images have been provided in a detailed report submitted to NMCG and these are images are also going to be made available in the public domain.

In addition to geocorrecting these images, we have also developed an Atlas to document the changes in the Ganga River over the last 5-6 decades in terms of channel morphology, landuse and landcover, river dynamics and associated issues. To capture the geomorphic diversity, ecological and socio-culture significance, and impact of human interventions, nine windows have been chosen from upstream to downstream: (1) Haridwar, (2) Bijnor, (3) Narora, (4) Kanpur, (5) Prayagraj, (6) Varanasi, (7) Patna, (8) Bhagalpur, and (9) Farakka. For each window, four pages have been dedicated to document (a) Geomorphic setting, (b) Channel Planform (as viewed from space) Changes, (c) Riverine Environment, and (d) Landuse and landcover changes. The Atlas has primarily used the data generated in this project in terms of morphodynamics and landuse and landcover changes. The interpretations made from this dataset are based on our process understanding of the Ganga River through previous research done by us and other workers.

Windows selected for the Atlas



Haridwar
- Foothills of Shivalik Ranges
- Bhimgoda barrage
- Prominent Hindu pilgrimage

Bijnor
- Bijnor barrage
- Haiderpur wetland

Narora
- Narora barrage
- Atomic Power plant
- Habitat for Ganga river Dolphin and crocodiles

Kanpur
- Leather industry
- Colonial architecture
- Kanpur barrage

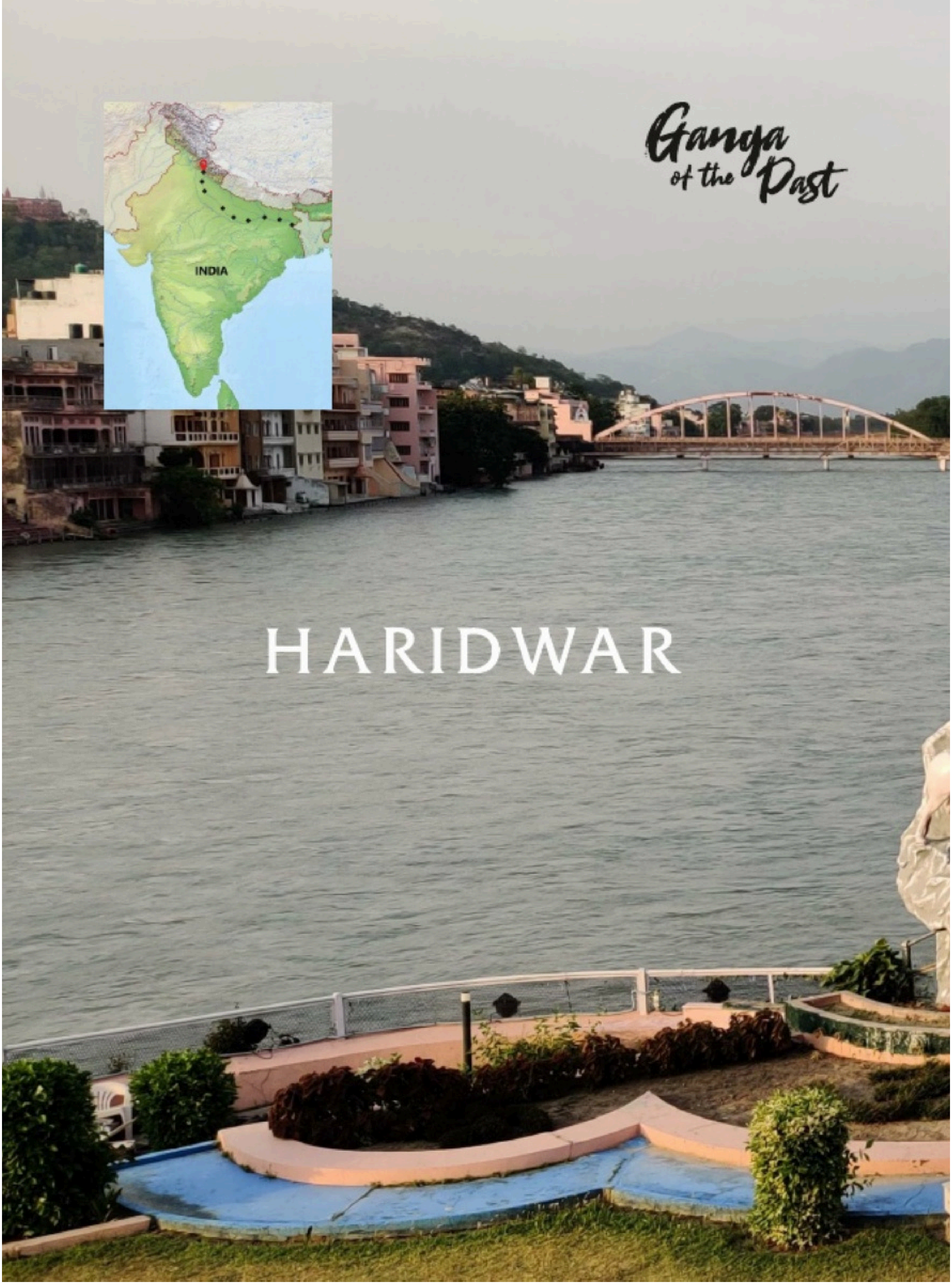
Prayagraj
- Sangam of Ganga-Yamuna
- Kumbh
- Most populous district of UP

Varanasi
- Important cultural heritage
- Turtle sanctuary
- Ghats along the river
- Founding centre of Buddhism

Patna
- Confluence of major rivers
- Large river islands
- Major ancient seat of learning
- One of the oldest continuously inhabited cities in the world

Bhagalpur
- Highly dynamic regime
- Silk industry
- Gangetic river dolphin

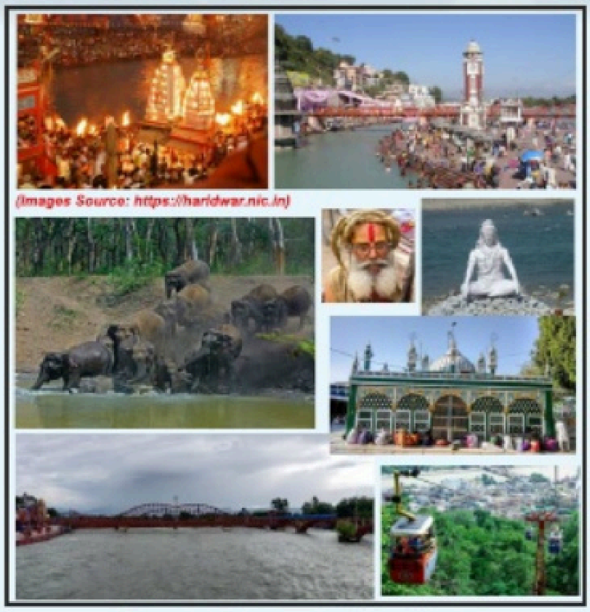
Farakka
- Farakka barrage
- Water sharing agreement with Bangladesh



HARIDWAR

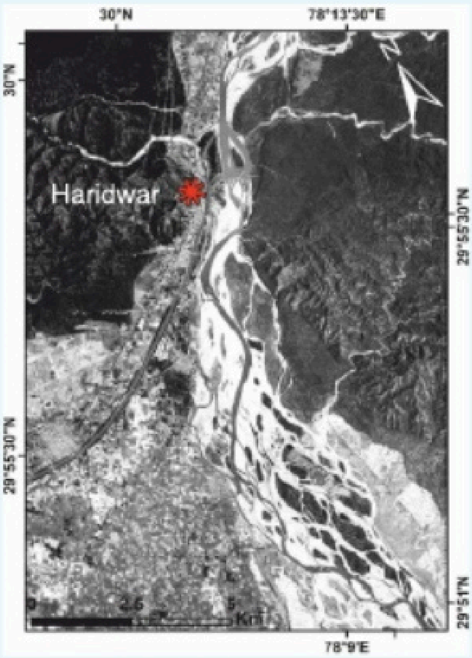
Geomorphic Setting

Haridwar, in the state of Uttarakhand is the second largest city in the state. It is situated on the right bank of the Ganga river, at the foothills of the Shivalik ranges. Haridwar is regarded as a holy place for Hindus, hosting important religious events and serving as a gateway to several prominent places of worship.

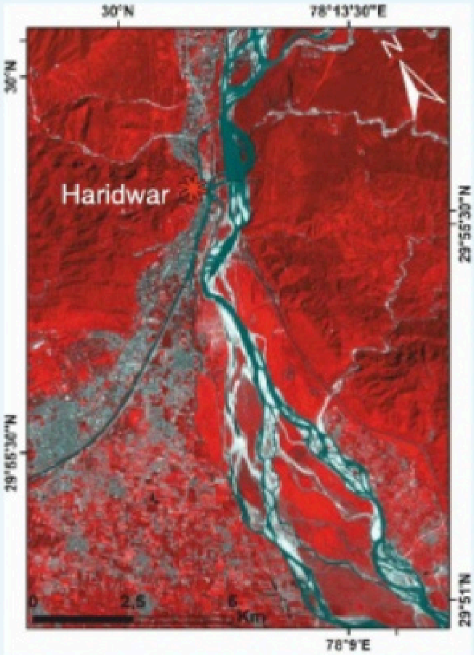


Places of interest in Haridwar

According to legend, it was in Haridwar that Goddess Ganga descended when Lord Shiva released the mighty river from the locks of his hair. The River Ganga, after flowing for 253 kilometres from its source at Gaumukh at the edge of the Gangotri Glacier, enters the Gangetic Plains for the first time at Haridwar.



1965 Corona image

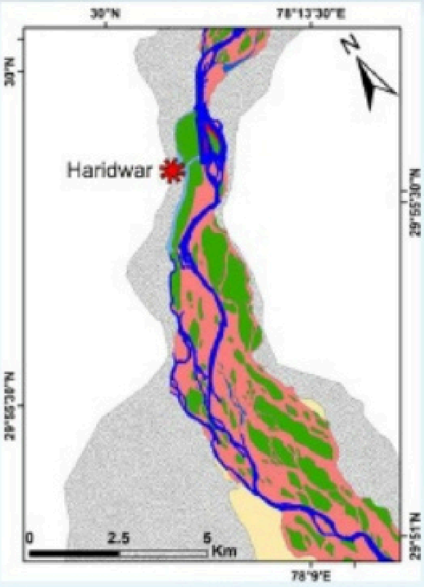


2018 Sentinel 2B FCC image

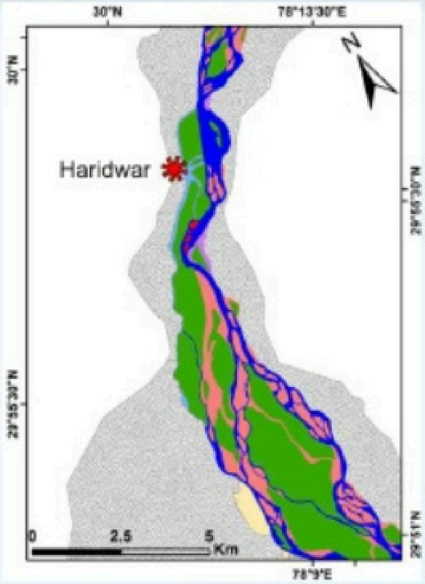
The Ganga river descends into the alluvial plain around Haridwar and the morphology of the river undergoes a significant change here from a confined channel upstream to an unconfined one but with a remarkable increase in braiding. Between 1965 and 2019, the river has undergone significant changes particularly in the downstream reaches.

A highly braided channel with a very wide channel belt has been transformed into much narrower and anabranched channel belts and large parts of the active bars are now converted to vegetated islands. This is clearly the manifestation of flow regulation upstream and channel stabilization measures in the downstream reaches.

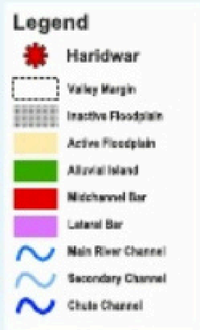
Channel Planform Changes



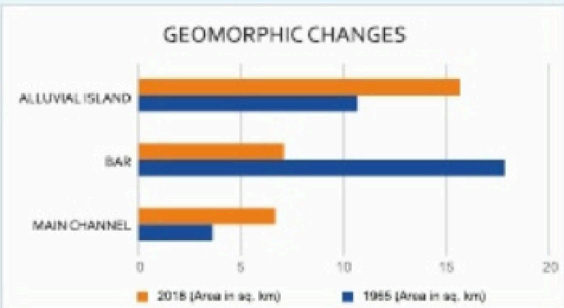
1965 Corona image



2019 Corona image



This reach is characteristic of a braided channel belt. The active depositional area manifested as bar area has decreased by a magnitude of sixty percent. The striking feature is the coalescing of small alluvial islands into large alluvial islands between 1965 and 2018. The area occupied by alluvial islands has increased by thirty five percent. These islands are stable forms which are resilient to erosion. The active channel belt width downstream of Bhimgoda Barrage has decreased from 1965 till 2018.

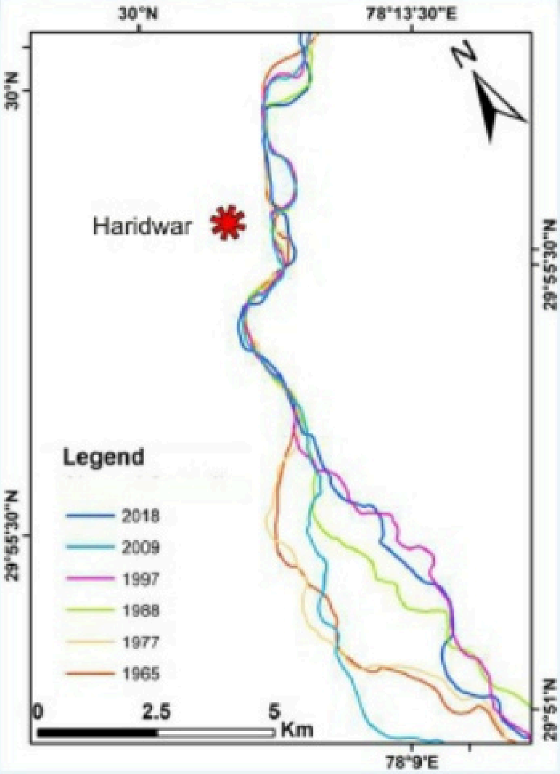


Geomorphic Class	1965 (area in sq.km)	2018 (area in sq. km)
Main Channel	3.63	6.67
Bar	17.85	7.07
Alluvial Island	10.67	15.66

Adjacent to the barrage, on the right bank of the river, barrage diverts water into the Upper Ganges Canal.

The Bhimgoda Barrage is 455 m long and sits at the head of a 23,000 km^2 catchment area. It contains 15 spillways gates and 7 undersluice gates, all 18 m wide. The flood discharge of the barrage is 19,300 m^3/s. The primary purpose for the barrage is irrigation but it also serves to provide water for hydroelectric power production and control floods.

Riverine Environment



The channel center line shift image of the six decades shows that the main channel of the Ganga River is highly migratory in this reach. The channel is confined to the valley margin upstream of the Bhimgoda Barrage and is also protected by embankments in the reaches immediately downstream of the barrage. About 3 kms downstream of the Bhimgoda Barrage, the channel belt expands considerably. Although there is no specific trend but the main flow has shifted from the right bank to the left bank between 1965 and 2018. The maximum lateral shift of the main channel is more than 3 km.

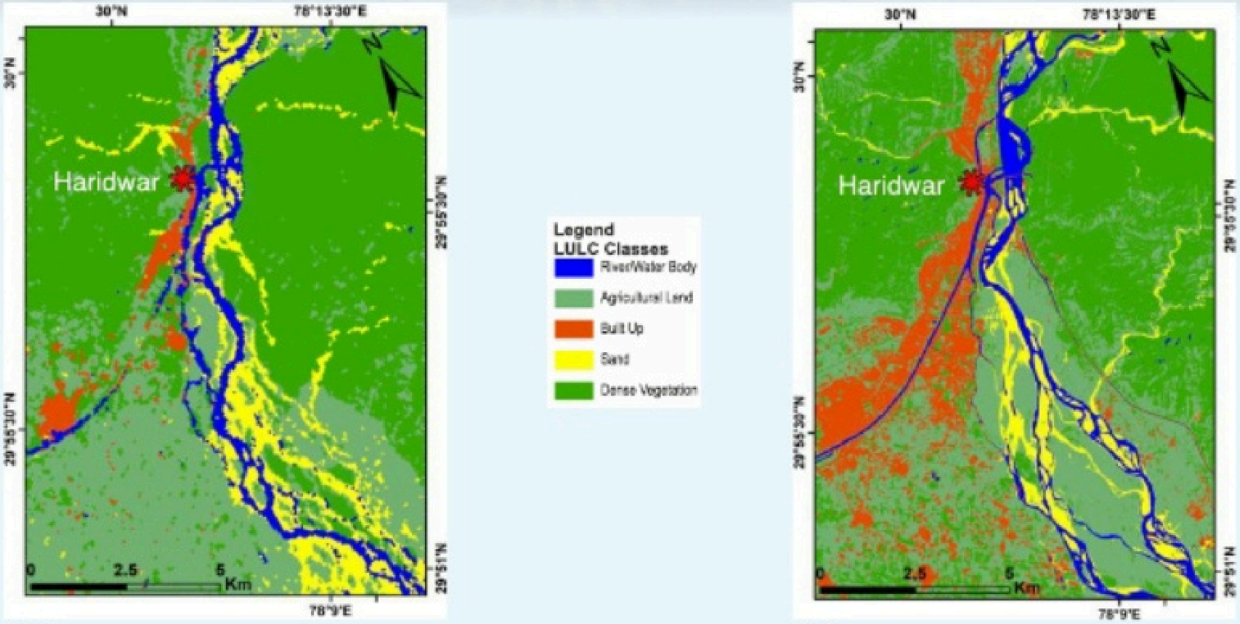
Such large scale channel shifting has often caused serious problems in this region in terms of bank erosion and destruction of infrastructures. A part of the reason for this instability is the sudden decrease in slope as the river enters in the flat alluvial plains and deposition of large quantities of sediments within the channel belt. This makes the channels shallower and prone to shifting through sedimentological readjustments (slope changes due to aggradation).

Channel Centreline shift in the last six decades

Leftovers after the rage of the river

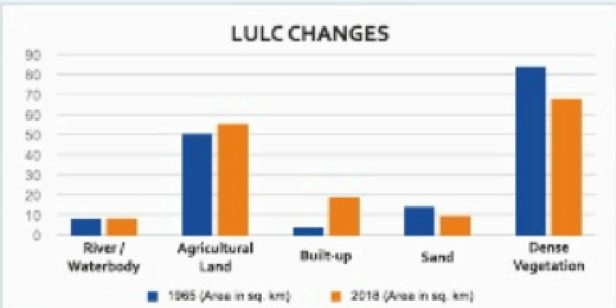
Destruction of the houses close to the river bank in the Kharakmaf area and that of the road in the Motichur Range are only some of the examples of the rage of the river. A large spread of the gravels on the banks indicates extensive sediment deposition in this region.

Landuse and Landcover Changes



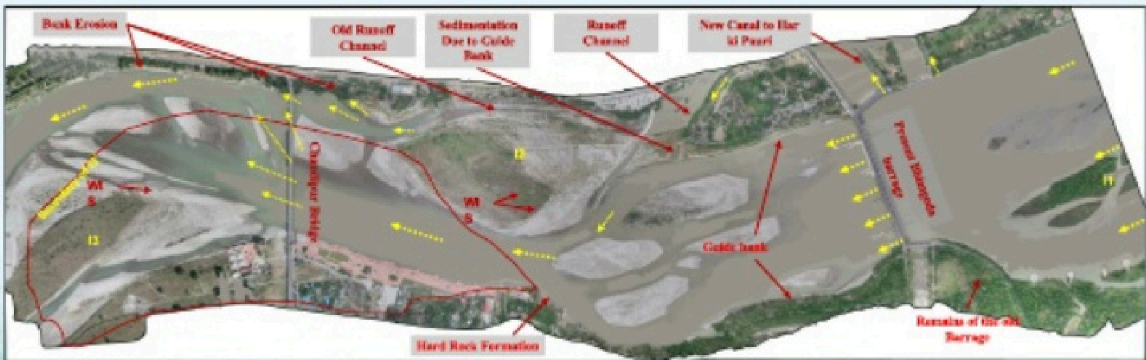
1976 | 2018

The area of river/ waterbody has been fairly consistent from 1976 till 2018. The area occupied by agricultural land has increased by ten percent between 1976 and 2018, at the cost of dense vegetation which has decreased by twenty percent. The built-up area has increased by a whopping eighty percent compared to 1976, towards the north western and south western portion of Haridwar Region. The area occupied by sand has decreased by nearly forty percent. These changes in landuse and land cover of the window around Haridwar reflect extensive urbanisation of this region.

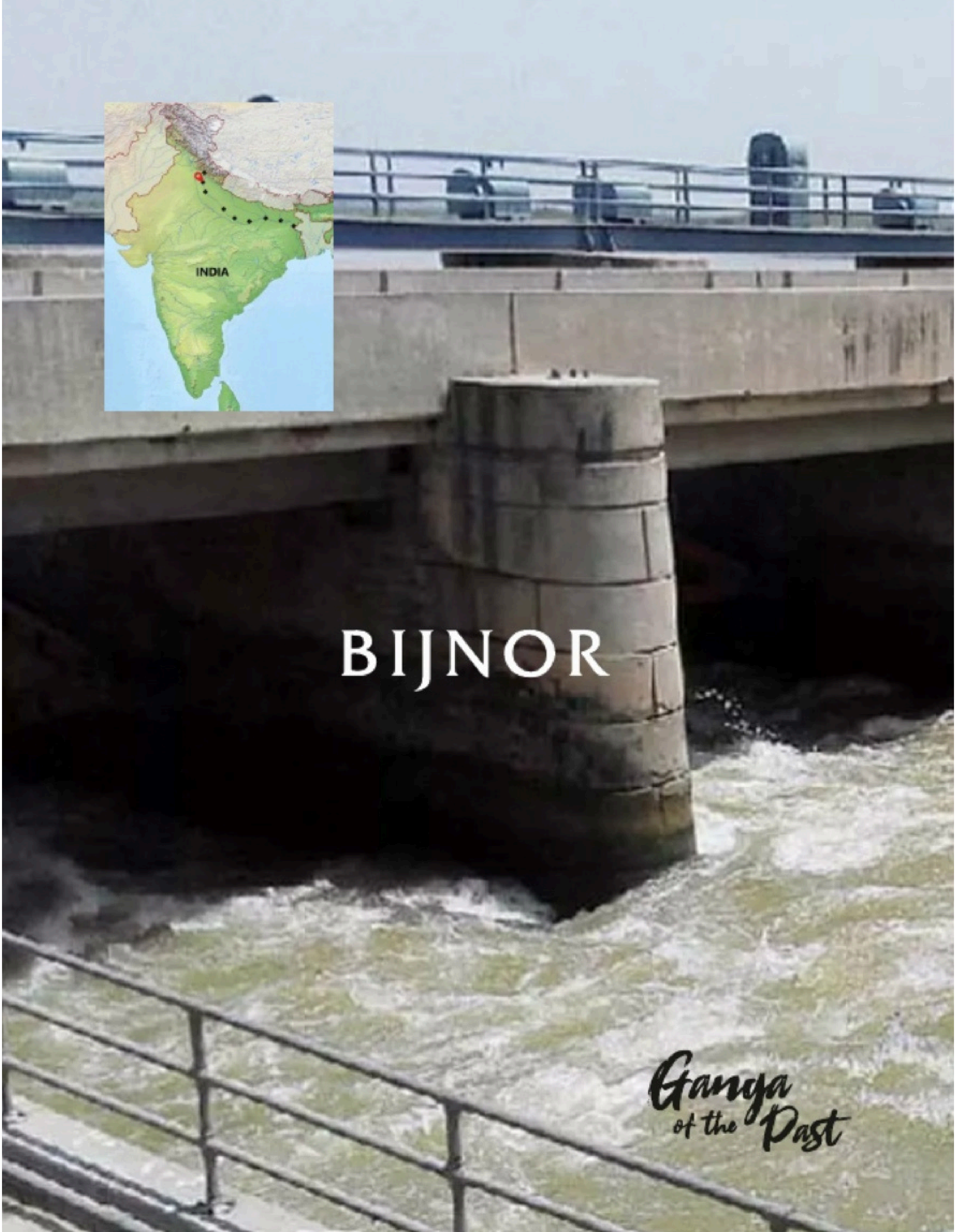


LULC Classes	1976 (area in sq.km)	2018 (area in sq. km)
River/Waterbody	8.05	8.51
Agricultural Land	50.2	55.35
Built-up	4.01	18.74
Sand	14.15	9.78
Dense Vegetation	83.52	67.55

A drone image showing large sand deposition downstream of the Bhimgoda barrage and the associated changes in channel morphology. The image also illustrates the erosion along the left bank and threats to the ghats.

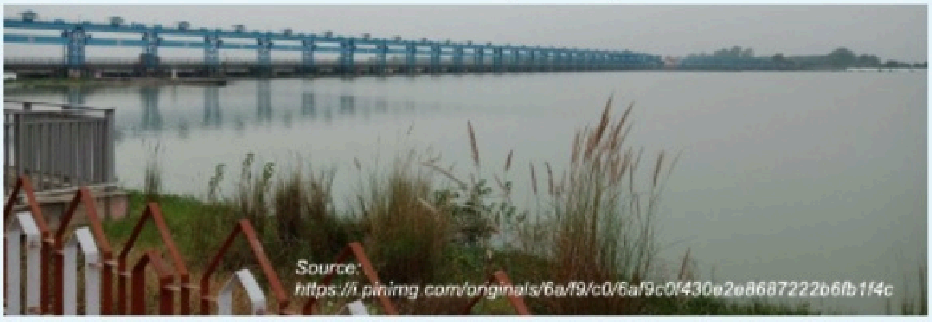


BIJNOR

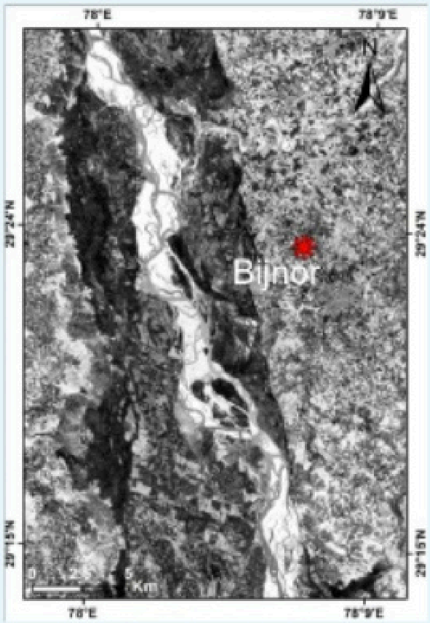


Geomorphic Setting

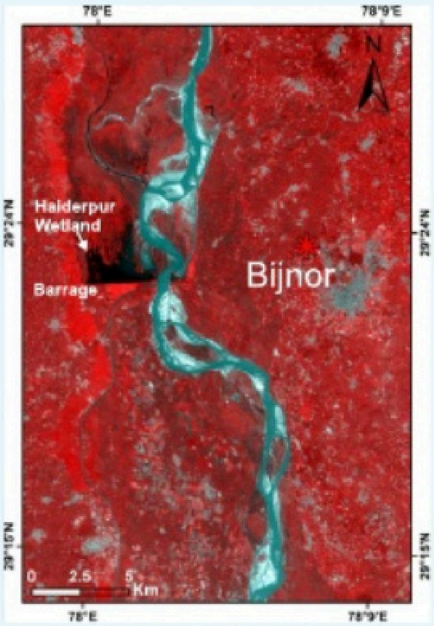
The city of Bijnor serves as a prominent pilgrimage destination in Uttar Pradesh for people from every major religion. The Ganga River forms the western boundary of the district, beyond which lie four districts of Dehradun, Saharanpur, Muzaffarnagar and Meerut. To the north and north-east is the hilly region of Garhwal, the dividing line being the sub-montane road, which runs from Haridwar along the foot of the Himalaya. To the east, the Phika river for the greater part of its course constitutes the boundary of the Bijnor district.



Bijnor barrage on Ganga



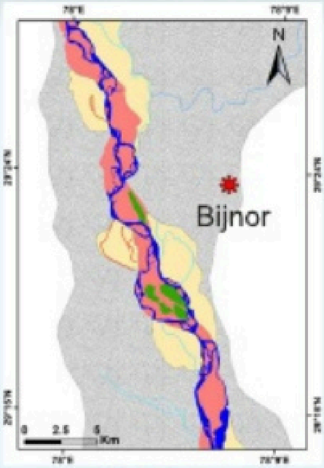
1965 Corona image



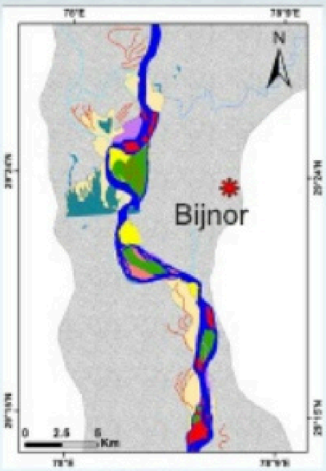
2018 Sentinel 2B FCC image

The 1965 image shows a braided-meandering channel in this stretch, which was transformed into a sinuous channel by 2018. A major anthropogenic intervention in this window is the Bijnor barrage since 1994 that has resulted in significant changes in channel morphology. The channel has relatively more anabranches in 1965 than in 2018. While the 1965 image shows extensive braid bars, the recent imagery is characteristic of a relatively medium sized point bars, lateral bars and mid channel bars. The bar area has significantly decreased by more than 60% during this period whereas the alluvial islands have increased by two-folds suggesting stabilization of sand bars. The active channel width has also decreased significantly between 1965 and 2018. Another major change is the development of the Haiderpur wetland in the post-barrage period which is a now a major ecological hotspot.

Channel Planform Changes



1965 Corona image

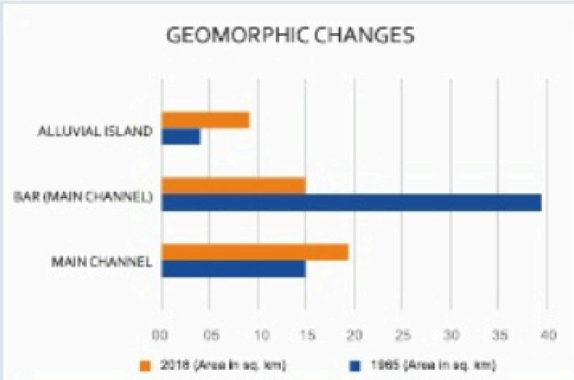


2019 Corona image

This reach is characteristic of a braided channel belt. The active depositional area manifested as bar area has decreased by a magnitude of sixty percent. The striking feature is the coalescing of small alluvial islands into large alluvial islands between 1965 and 2018. The area occupied by alluvial islands has increased by thirty five percent. These islands are stable forms which are resilient to erosion. The active channel belt width downstream of Bhimgoda Barrage has decreased from 1965 till 2018.

The Ganga River in the Bijnor window shows remarkable changes in planform during the period 1965 and 2018. A dominantly braided-anabranching river has been transformed into a wide braided channel with a much reduced anabranching. Several small mid channel bars have disappeared particularly in the stretch upstream of the Bijnpor barrage that came up in 1994.

Another interesting feature of ths stretch is the man-made Haiderpur wetland that came into existence in 1984 after the construction of the Bijnor barrage started in 1980-81. This wetland, falling under the Hastinapur Wildlife Sanctuary, is fed by the Ganga river through the releases from the barrage, apart from the inflows from the Solani river. The wetland is spread into more than 3000 acres of area with variable depth of water and supports a very rich biodiversity.



Geomorphic Class	1965 (area in sq.km)	2018 (area in sq. km)
Main Channel	15	19
Bar (Main Channel)	39	15
Alluvial Island	4	9

Morphometric data on planform dynamics shown above shows a significant decrease in bar area from 1965 to 2018 and a sizable increase in alluvial islands suggesting that part of the reaches are getting stabilised and active channel deposition has either reduced or submerged, possibly after the construction of the barrage. This observation is also supported by an increase in the channel area between 1965 and 2018.

Historical Fort Near Bijnor

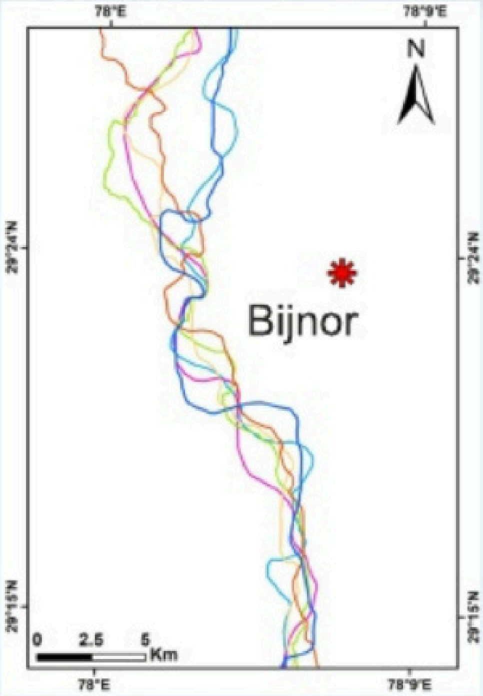
The legacy of the Mughals and the Nawab rulers can still be seen in the mosques of Bijnor. These elegant sites of Muslim worship reflect the architectural tastes of the long-gone royalty.

Jama Masjid, Teli Wali Masjid, Hadishah, Markaz Masjid and Bahar Wali Masjid are some of the well-preserved mosques in Bijnor.

Daranagar was of historical importance during Mahabharata. When the war between Kauravas and Pandavas began, both sides wished to safeguard their wives and children under the protection of Vidur Kuti before starting the war.

Vidur Kuti Temple

Riverine Environment



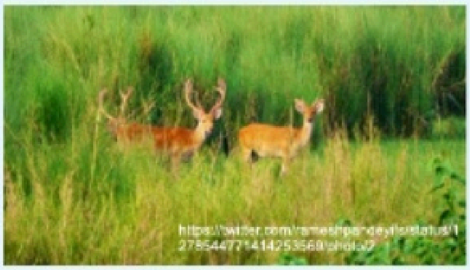
Channel Centreline shift in last six decades

The channel centre line shift map of six decades shows that the main channel of the Ganga River is highly migratory in this reach. A significantly high sinuosity is observed post 1988 which can be attributed to the construction of the Madhya Ganga Barrage starting in 1980-81 and completed in 1994. The reaches upstream and the downstream of the Barrage show significantly high sinuosity.

Legend

- 2018
- 2009
- 1997
- 1988
- 1976
- 1965

Sherkot is famous for brush business whereas Nagina area of the district is famous for the handicraft work.



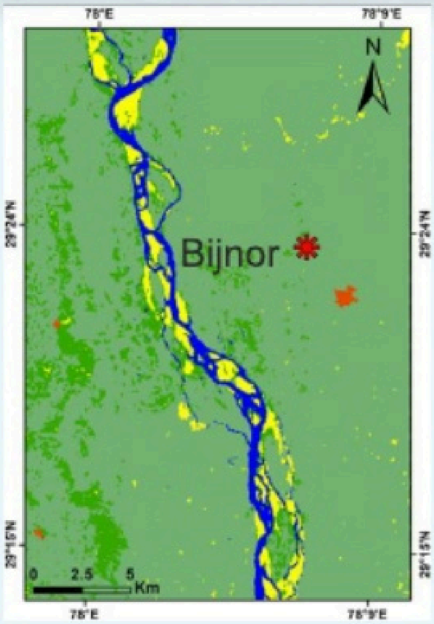
Amazing transformation underway at Haiderpur. Its turning into an emarald green grassland.

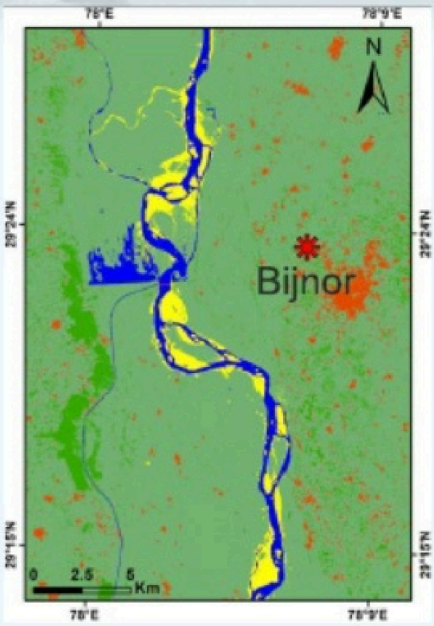
Bijnor has 2 of India's top 5 sugar mills

Haiderpur Wetland is part of Hastinapur Wildlife Sanctuary in Muzaffarnagar District situated next to Bijnor Ganga Barrage.

The main economy of district Bijnor is cane productions besides some agro industrial units.

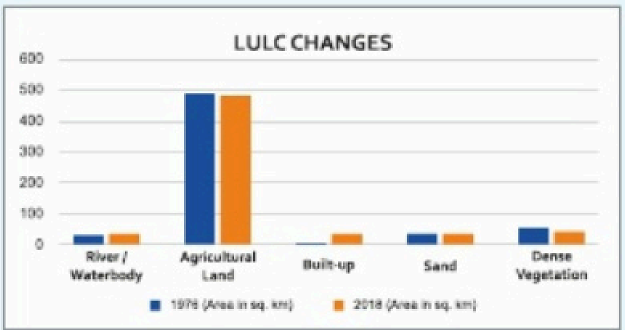
Landuse and Landcover Changes



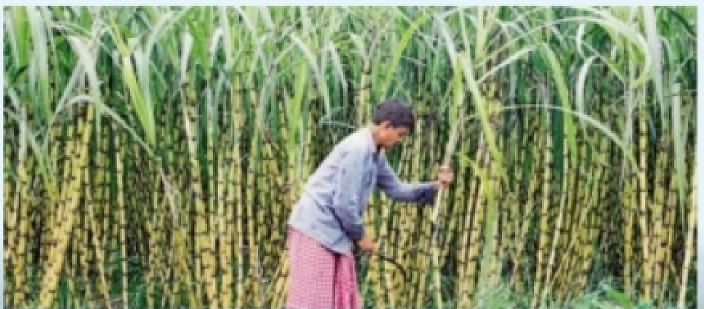


1976 Landsat Image **2018 Sentinel Image**

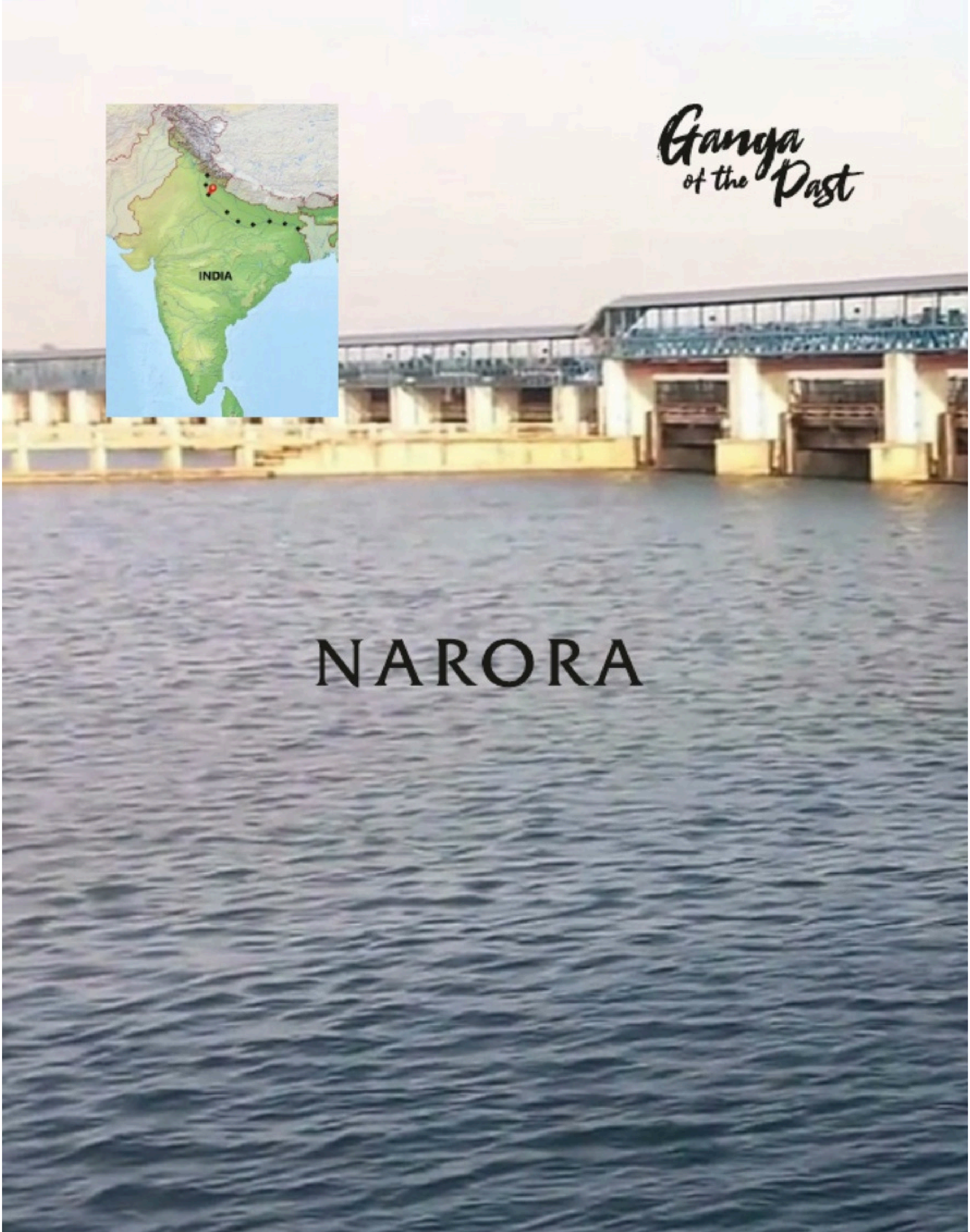
Two most important LULC changes in this window between 1976 and 2018 include (a) decrease in dense Vegetation by more than 30%, and (b) significant increase in the built up area particularly on the eastern side reflecting urbanisation around the Bijnor town. We document a 20-fold increase in the built-up area between 1976 and 2018. The areas of the agricultural land and the sand bodies have been fairly consistent in this period.



LULC Classes	1976 (area in sq.km)	2018 (area in sq. km)
River/ Water body	19	23
Agricultural Land	498	491
Built-up	1	22
Sand	22	22
Dense Vegetation	55	37



The main economy of the district is cane production.

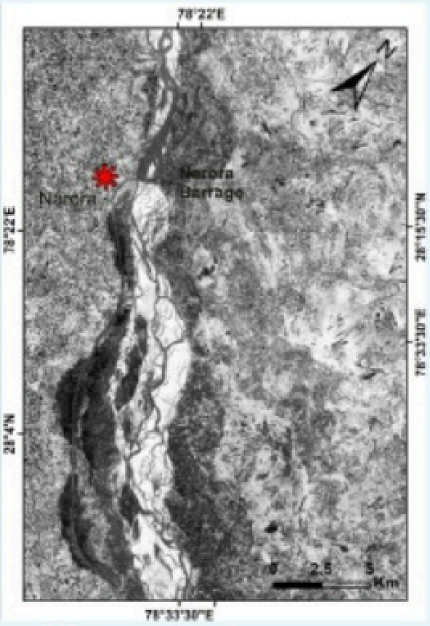


Ganga of the Past

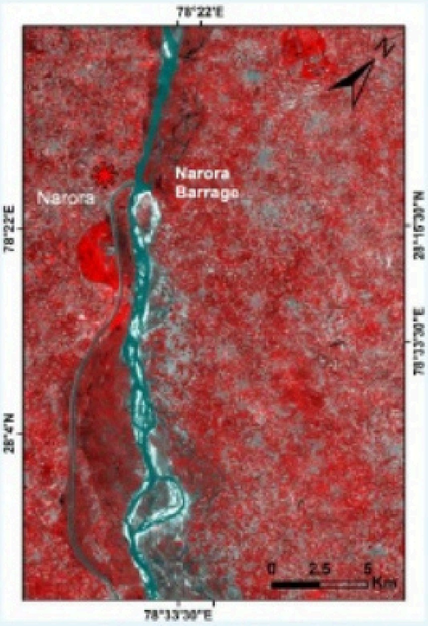
NARORA

Geomorphic Setting

The Ganga river near Narora is marked by one of the very early intervention - the Narora barrage that was constructed during 1962-67. Apart from regulating the water flow, the Narora barrage has a unique feature- a fish pass - to facilitate the fish to travel from downstream to upstream. The Narora town is located nearly 150 km from the National Capital Delhi, and is an important destination for the ritual of Ganga Snana by millions of pilgrims from nearby areas.



1965 Corona image

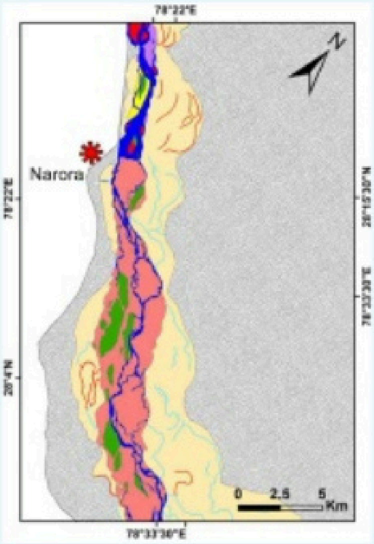


2018 Sentinel 2B FCC image

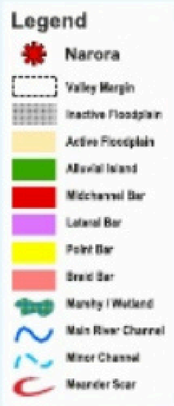
The satellite images of the Ganga river around Narora from Corona as well as the Landsat post-date the construction of the Narora barrage and therefore, they both show this intervention quite clearly. However, we note remarkable changes in river morphology during this period. The 1965 Corona image represents the early stages of the barrage construction and while the upstream reaches still show some confinement, the reaches downstream of the barrage were still quite free flowing with a wide channel belt created by repeated channel migration. Large active bars and multi-channel system of the Ganga show very little modification from the expected morphology in this reach.

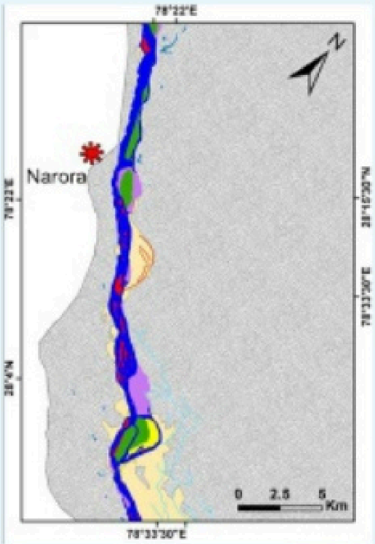
However, the 2018 image show a remarkable straightening of the river stretch upstream of the barrage apparently due to confinement by the embankments. The reaches downstream of the barrage show narrowing of the channel belt due to channelization of the flow possibly through river training works. Detailed morphological changes are further shown on the next page.

Channel Planform Changes



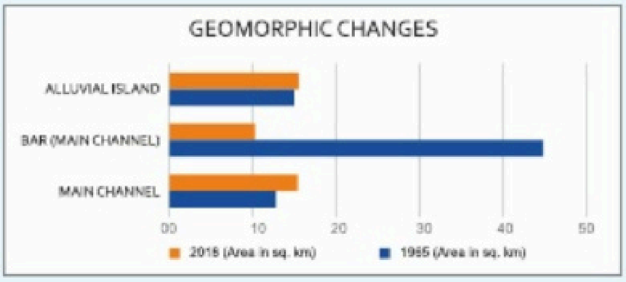
1965





2018

The channel belt in this window is unconfined with respect to the valley margin, positioned towards the western side of the valley margin. The 1965 map shows that the river is bifurcated and the channel belt is braided, with numerous braid bars, small point bars, mid channel bars and some alluvial islands. The 2018 map shows some remarkable changes in channel morphology compared to 1965 - the most important being a sharp reduction in channel belt area as well the active floodplain width. The river is now confined into a rather narrow channel belt and is characterized by small mid channel bars, lateral bars, point bar and alluvial islands. The bar area has decreased four folds from 1965 till 2018. The alluvial island area has increased by a minor seven percent from 1965 till 2018.



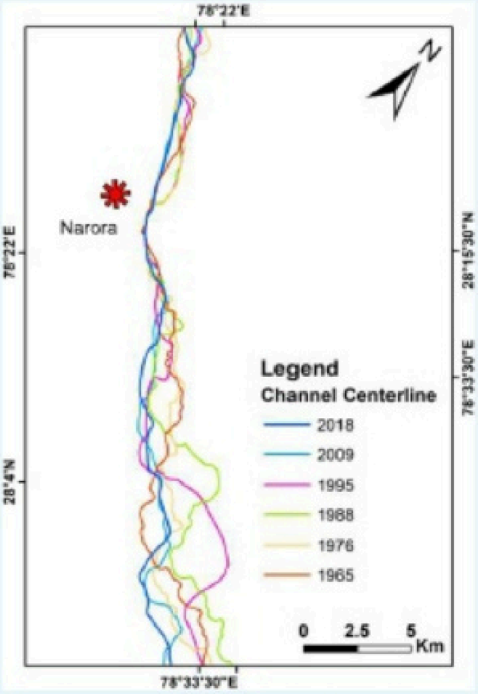
Geomorphic Class	1965 (area in sq.km)	2018 (area in sq. km)
Main Channel	12.37	15.32
Bar	44.53	10.61
Alluvial Island	15.02	16.14

(Source:https://www.indianreptiles.org/sp/25/Gavialis-gangeticus)

With a wide range of bird diversity, the wetlands of 265 km^2 of upper Ganga, from Brijghat to Narora stretch were declared as Ramsar site in 2005.The river provides habitat for IUCN Red listed Ganges River Dolphin and Gharial Crocodile.

It is noteworthy that the even though the Narora barrage caused some loss of longitudinal connectivity, the impoundment of water upstream of the barrage has helped to maintain the suitable habitat for dolphins to thrive. As a consequence, it resulted in a significant growth in the dolphin population particularly during the period 1993-2010.

Riverine Environment

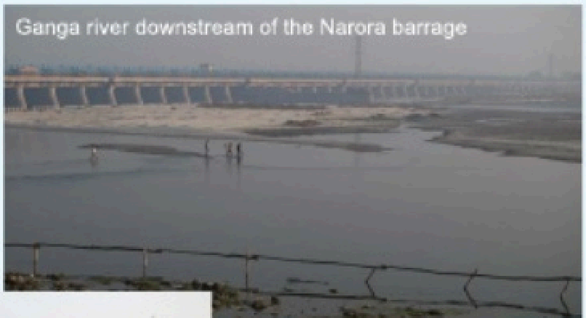


Channel centerline shift in last six decades

The channel center line shift image of the six decades shows that the main channel of the Ganga River has been highly migratory in this reach, specifically downstream of the Narora Barrage. Post-barrage construction, the channel has been straightened upstream of the barrage, but still maintains a meandering path downstream of the barrage with small anabranches. However, the channel center line is much less sinuous downstream of the barrage compared to the pre-barrage period possibly because of regulated flows through the barrage. In summary, we infer a much reduced river dynamics through time in reaches both upstream and downstream of the barrage which has seemingly played a significant role in influencing the river processes .

As evident from the geomorphic maps, a significant reduction in active floodplain width coupled with reduced channel dynamics and regulated flows has influenced the morphodynamics of the Ganga river in this region. Indirectly, the river dynamics also influences the variation in active floodplain width as well as flooding extent on either side of the channel. It has also been established that changes in river morphology including its floodplain can modify the habitat conditions e.g. total population, distribution along the river, for major aquatic fauna such as dolphins for which this region is known for. Such relationship between geomorphology and ecology has not been explored much in case of the Ganga river.

Shree Ganga Dham Rajghat, Narora

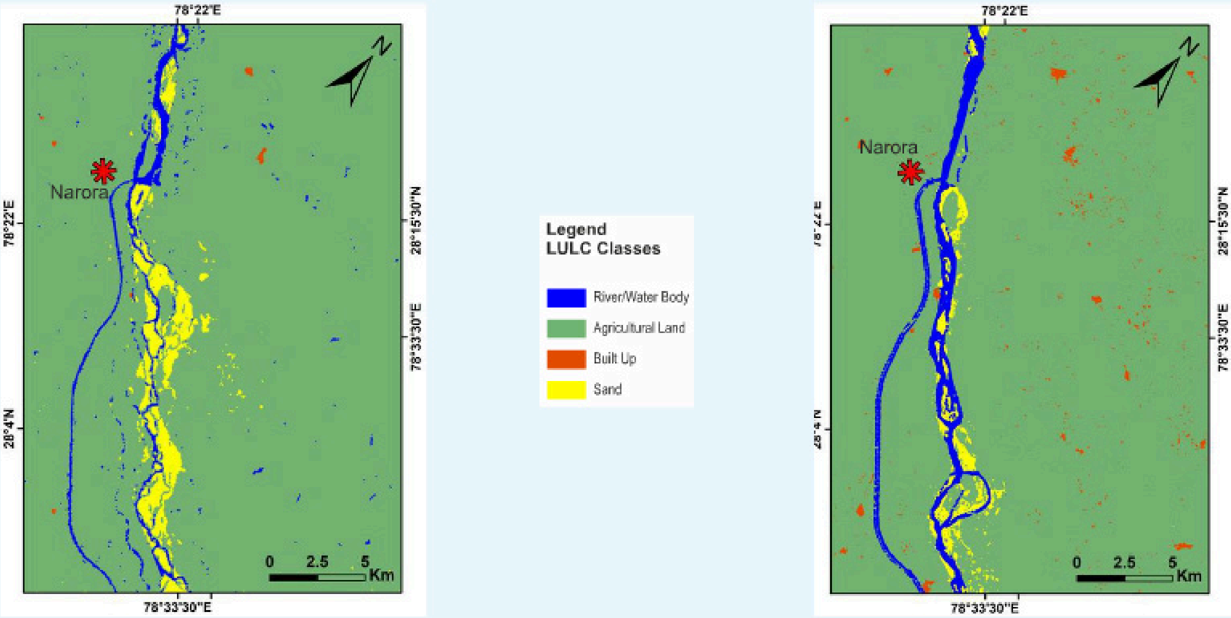


Ganga river downstream of the Narora barrage

Bank protection measures around Narora

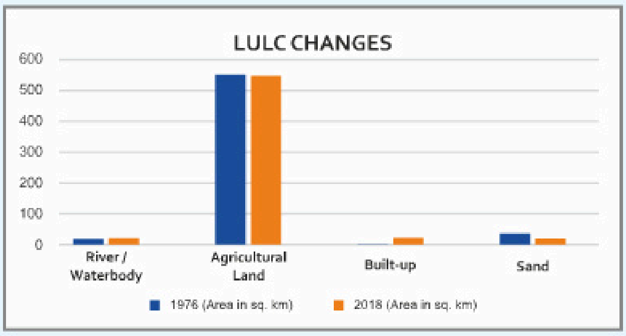
View of the Ganga river upstream and downstream of the Narora barrage depict the influence of the barrage on channel morphology. The Rajghat site maintains a good flow conditions while the downstream reaches are very shallow and highly aggrading. Channel migration also causes severe bank erosion at several places which need to be protected because of habitations close to the river.

Landuse and Landcover Changes

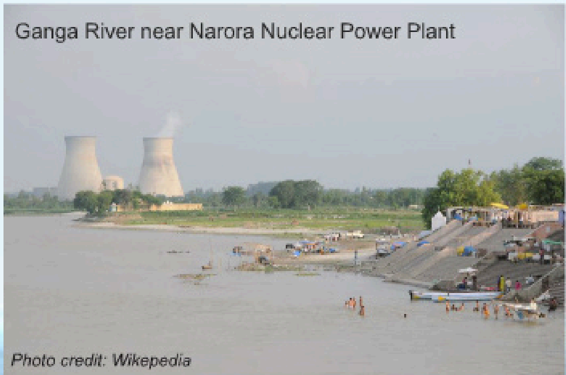


1976 Landsat Image **2018 Sentinel Image**

Landuse and landcover changes in this window have attracted a lot of attention, the stretch from Brijghat to Narora being a Ramsar site. The construction of the Narora barrage and the Atomic Power Plant around Narora has led to rapid urbanisation of this area and this has threatened the ecological balance in this region. Previous studies in this region have also called for an urgent need for afforestation and sustainable landuse planning.



LULC Classes	1976 (area in sq.km)	2018 (area in sq. km)
River/Waterbody	11.32	12.78
Agricultural Land	556.16	552.09
Built-up	0.53	13.26
Sand	21.28	12.77



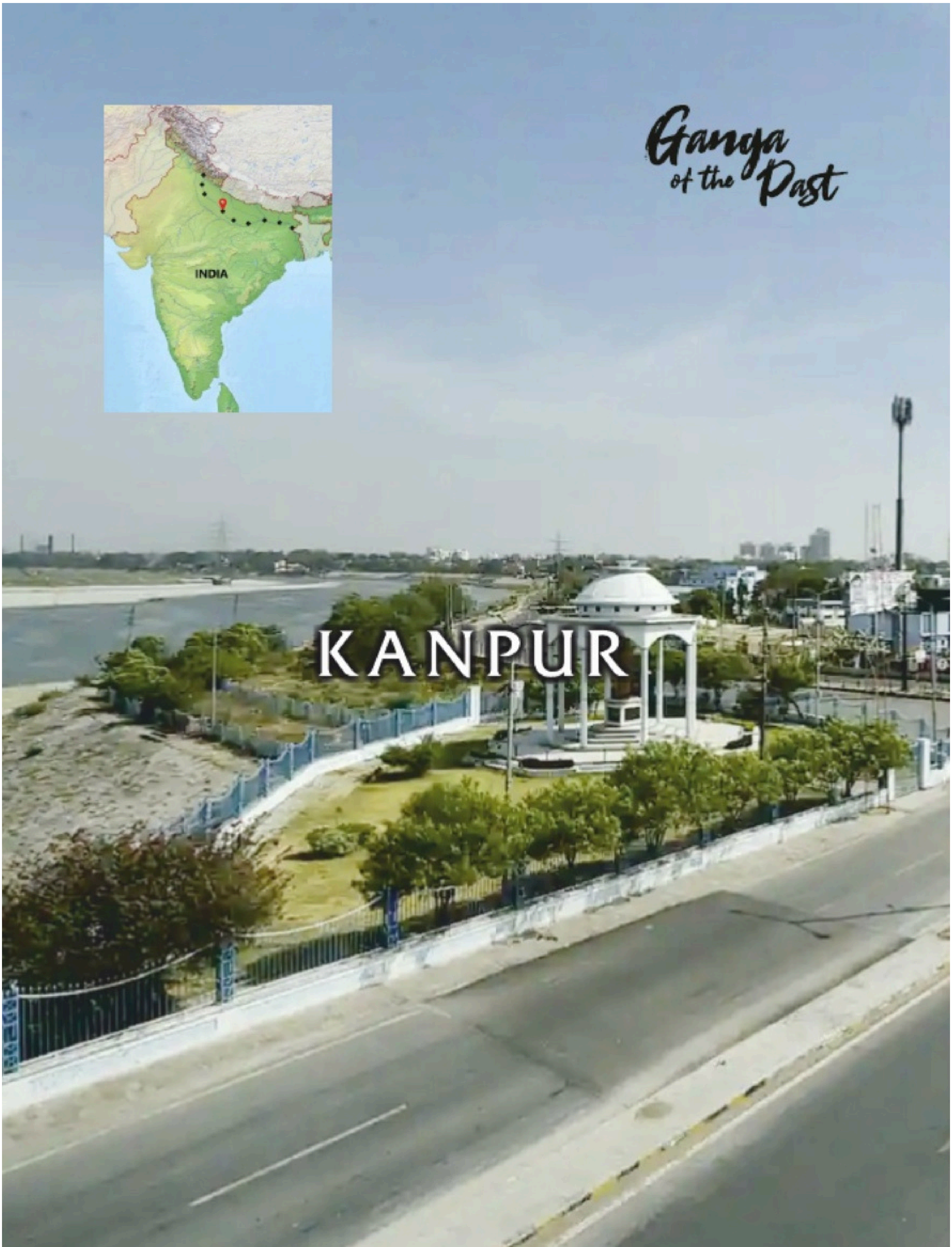
Ganga River near Narora Nuclear Power Plant

Photo credit: Wikepedia

A comparison of the LULC maps of 1976 and 2018 shows that the built-up area has increased from a negligible 0.56 sq km to 13.26 sq km, from 1976 till 2018.

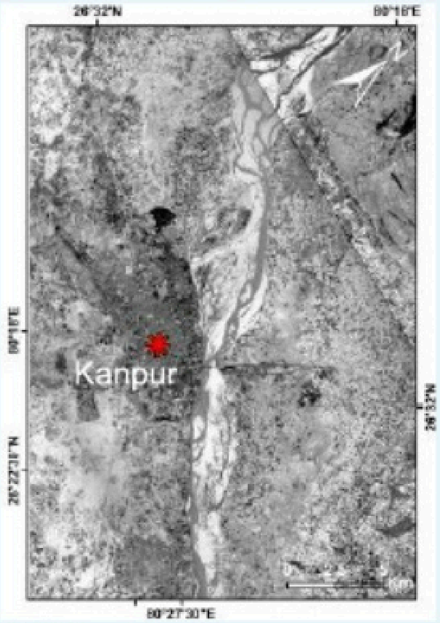
The area occupied by the agricultural land has been modified by a minor one percent at the cost of increase in the built-up area.

The area occupied by sand has also decreased by forty percent from 1976 till 2018. While the overall river water body area has been fairly consistent from 1976 till 2018, spatial variability along the river is notable.


INDIA
Ganga of the Past
KANPUR

Geomorphic Setting

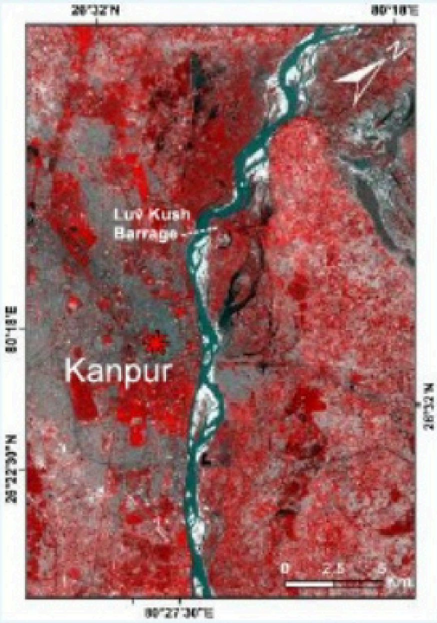
Kanpur, formerly known as Cawnpore, is the second most populous city in Uttar Pradesh and lies in the Lower Ganga-Yamuna Doab on the Ganges. The surrounding region is a fertile stretch of alluvial plain between the Ganga and Yamuna rivers. It is watered by tributaries of the two rivers and by the Lower Ganges Canal. Crops grown include wheat, gram, jowar and barley. There are mango and mahua groves and a dhak forest. Bithoor, a historic town on the Ganges just to the north of Kanpur, is a Hindu holy place. The town was also one of the focal points during the early stages of the Indian Mutiny (1857–58). The presence of a large number of tanneries in the city has helped it earn the moniker 'Leather Capital of India'.



1965 Corona image

The Ganga river at Kanpur flows in NW-SE direction and the river is characterized by a multi-channel system.

The anthropogenic interventions on the Ganga river around Kanpur include a recently constructed barrage in the year 2000 and a couple of rail/road bridges across the river. The position as well as the morphology of the river has changed significantly during the period 1965-2018 as illustrated by the Corona and Sentinel images respectively.

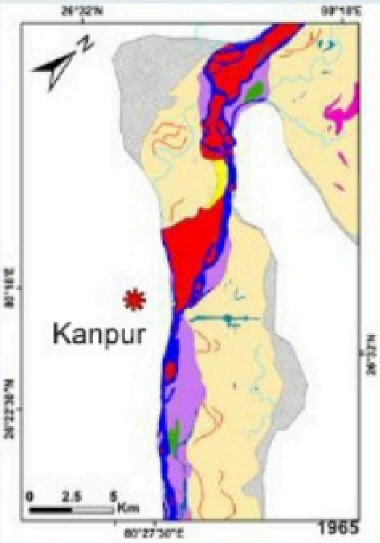


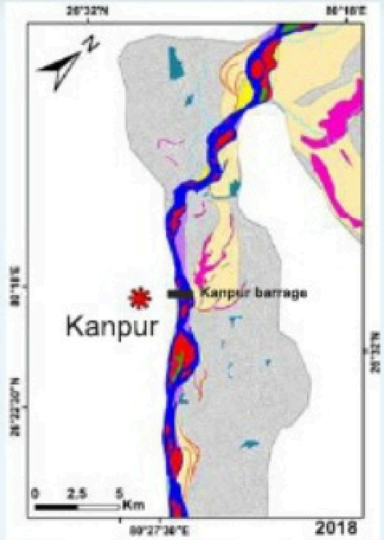
2018 Sentinel 2B FCC image

Ganga Barrage Kanpur, also known as Luv Kush Barrage is a bridge and a dam across the Ganges in Azad Nagar-Nawabganj in Kanpur. This 621 m bridge serves as a four-lane highway bypass for NH 91.

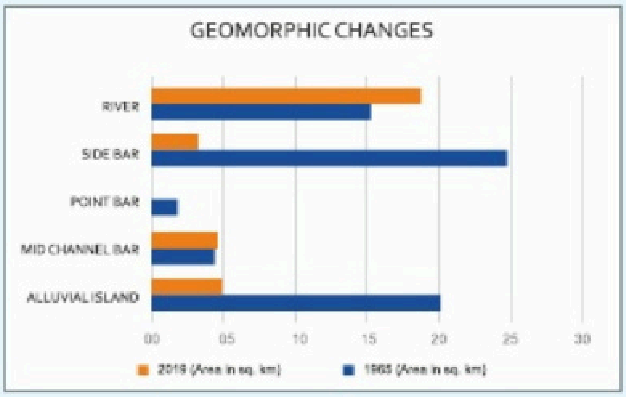
The origin of Holi mela has been traced back to 1942 when the Britishers imposed a ban on playing Holi and arrested people for disobeying orders. Enraged over the arrests, the city denizens played Holi for seven days continously for the release of the protestors. Since then **Ganga Mela** is celebrated to commemorate the victory of Indians over the British rule.

Channel Planform Dynamics

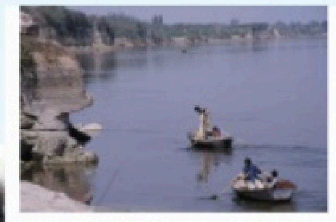




The Ganga river in this window is highly braided and is partly confined by 10-15m high cliffs along its southern valley margin. The planform map based on 1965 image shows large mid channel bars, large lateral bars and very wide active floodplain, while the 2018 map has fairly smaller mid channel bars and lateral bars and a much depleted active floodplain. The total bar area has decreased by 73% whereas the areas occupied by the main channel and the alluvial islands have been fairly consistent. The active channel belt width has decreased in the last 60 years. Oxbow lakes and meander scars close to the barrage site in the 2018 image are manifestations of the older active channel belt of 1965, that has moved NW to its current position.



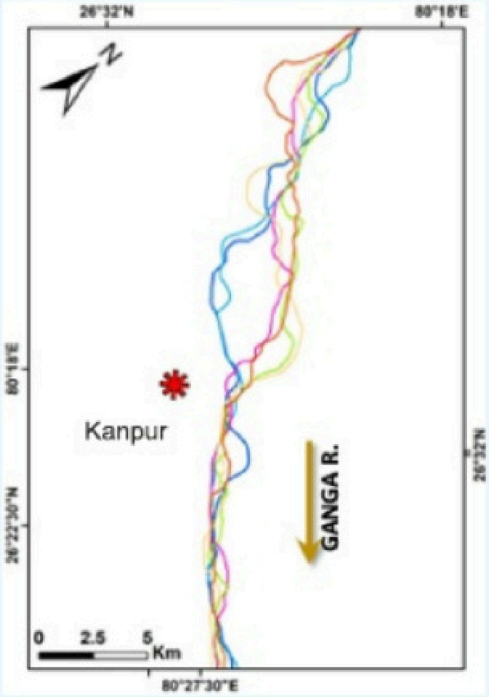
Geomorphic Class	1965 (area in sq.km)	2019 (area in sq. km)
Alluvial Island	20.62	4.98
Mid Channel Bar	4.31	4.51
Point bar	1.73	0
Side bar	24.69	3.23
River	15.5	17.63



Riverine Environment

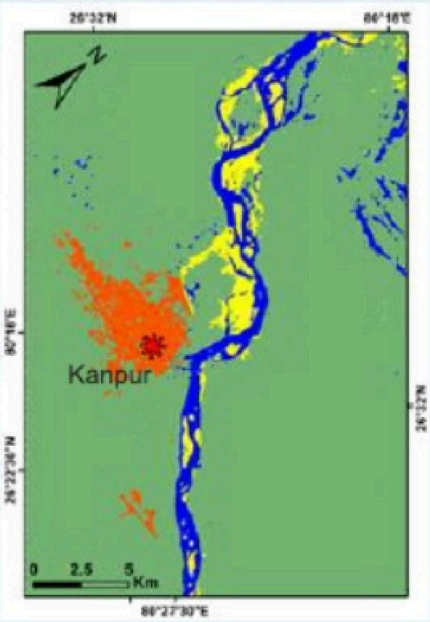
The channel center line shift image of the six decades shows that the main channel of the Ganga River is highly migratory in this window, particularly in the reaches upstream of the barrage that became operational in 2000 (the construction started in 1995). The reaches upstream of the barrage are characterised by a relatively higher sinuosity and channel migration of the order of 5 kms is noted between 1965 and 2018. The river has been relatively stable in the reaches downstream of the barrage apparently because the flow is regulated since 2000.

Because of the highly asymmetric profile of the river channel (deeper along its SW margin), the Ganga river is known to have shifted SW in pre-historic times and has also been incising its southern bank creating 10-15 high cliffs. The SW migration of the river seems to have continued in recent times as well particularly in the reaches upstream of the barrage. In contrast, the NE bank of the river is flat and is often inundated by flood waters during the monsoon.

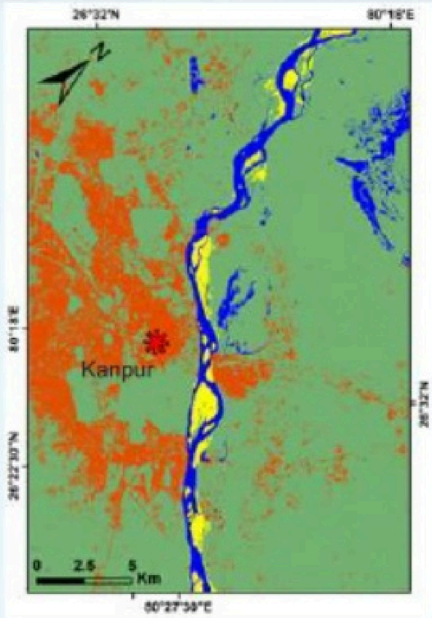


Channel Centreline shift in last six decades

Landuse and Landcover Changes

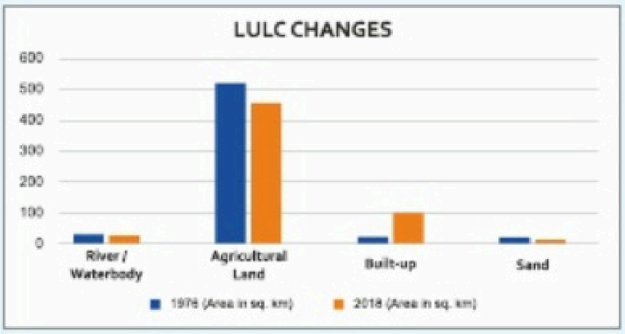


1976 Landsat Image



2018 Sentinel Image

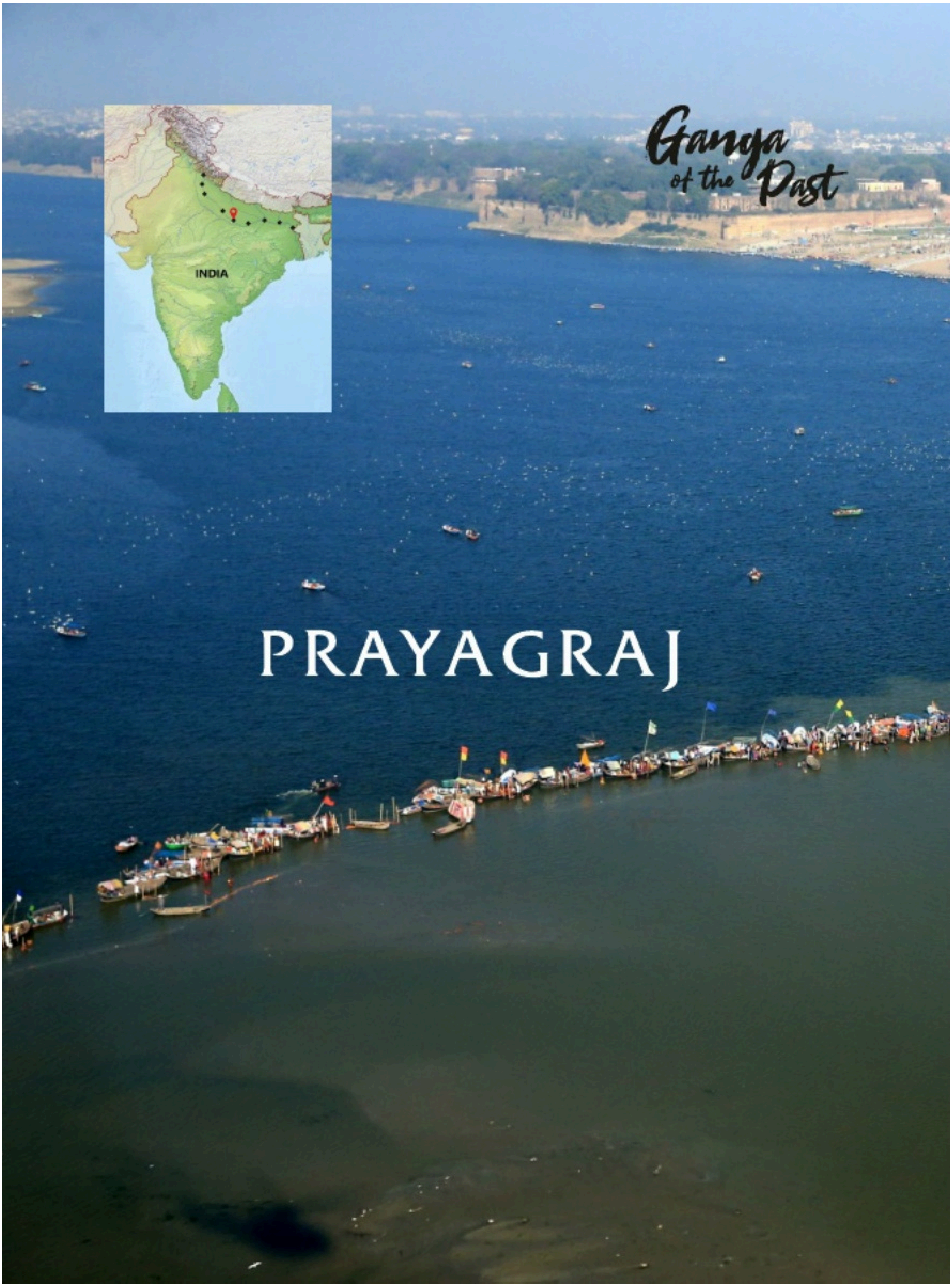
The most remarkable change in this window in terms of landuse and land cover changes is the dramatic expansion of the urban area. A comparison of the LULC maps derived from 1976 and 2018 satellite images shows a five-fold increase in urban area in this window. The urban expansion has occurred both in the north west, south west and also towards the south eastern side as a manifestation of the new Trans-Ganga city being developed since 2014. Further, the area occupied by sand has decreased by nearly 40% between 1976 and 2018. The area occupied by river/water body has decreased by 12%. The area occupied by agricultural land has also decreased by 12% mostly converted to built-up area. A major impact of the increased urbanization in this window has been on the water quality of the Ganga river - drone image of a small stretch of the Ganga river around Kanpur shows the different shades of water reflect the pollution level cause by the effluent discharged from Kanpur city through numerous drains.



LULC Classes	1976 (area in sq.km)	2018 (area in sq. km)
River/Waterbody	30.96	27.39
Agricultural Land	521.22	458.72
Built-up	22.14	100.9
Sand	20.36	11.95

Drone image of the Ganga river (2015)

PRAYAGRAJ



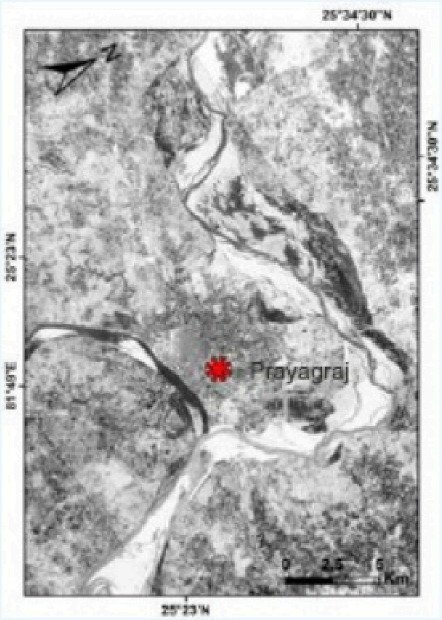
Geomorphic Setting

Prayagraj (also known as Allahabad, Illahabad and Prayag) is the 13th most populous district in India. To its south and southeast is the Bagelkhand region; to its east is middle Ganges valley of North India, or Purvanchal; to its southwest is the Bundelkhand region; to its north and northeast is the Awadh region and to its west along with Kaushambi it forms the part of Doab i.e. the Lower Doab region.

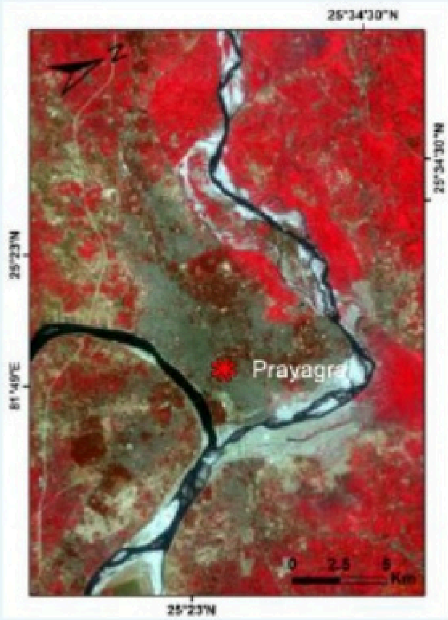
The city is the judicial capital of the state of Uttar Pradesh with Allahabad High Court being the highest judicial body in the state.

The city lies close to **Triveni Sangam**, the confluence of the Ganga and the Yamuna and is considered to be a major spiritual center for Hindus.

The confluence of the Ganga and the Yamuna.



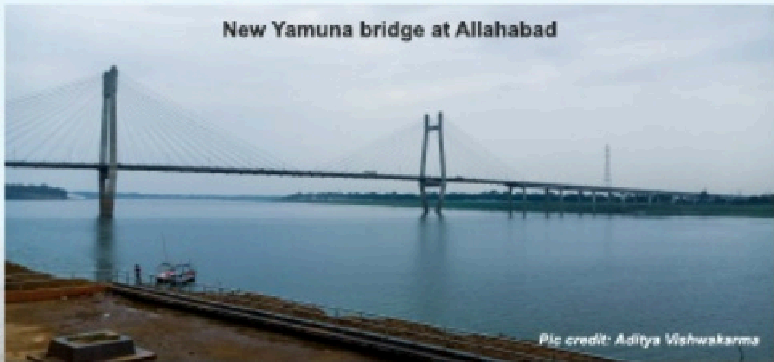
1965 Corona image



2018 Sentinel 2B FCC image

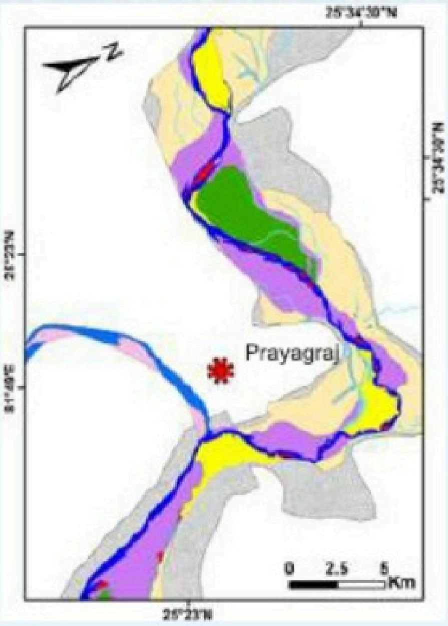
The most important geomorphic feature of this window is the confluence of the Ganga with the Yamuna river. We note significant changes in the morphology of the Ganga river around the confluence zone and interestingly not so much in the Yamuna river during the period 1965-2019. While the Ganga river has maintained its general form, and position of the meanders, there are significant reductions in the meander wavelength, width of the channel belt and active floodplain width . In terms of anthropogenic interventions, there are two long bridges on the Yamuna, Old Naini bridge (constructed in 1927, rail/road bridge) and the new Yamuna road bridge that came in existence in 2004. A new bridge across the Ganga river is under construction at Phaphamau, scheduled to be completed in 2021.

New Yamuna bridge at Allahabad

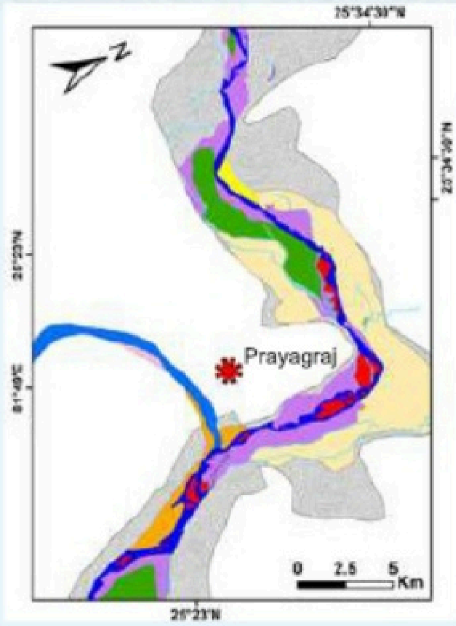


Pic credit: Aditya Vishwakarma

Channel Planform Changes



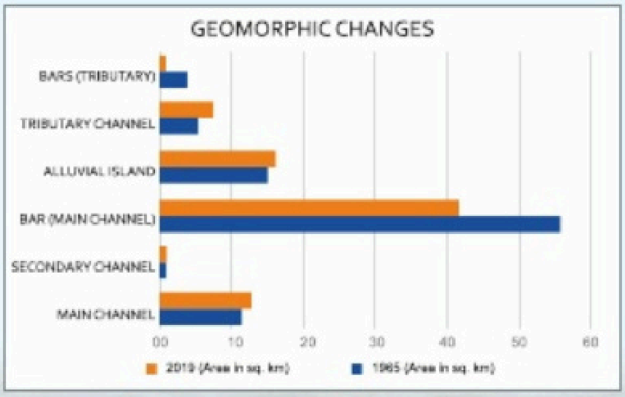
1965



2019

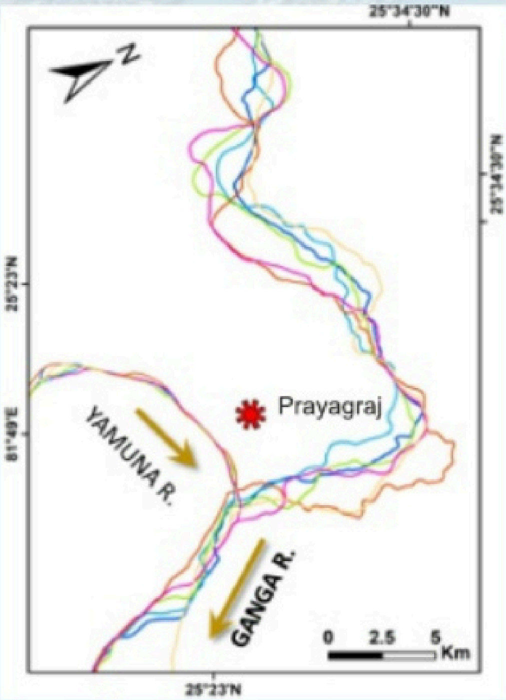
This window is characteristic of a meandering-anabranching channel belt and the confluence of the tributary river Yamuna from the south west. The channel belt of Ganga is partly confined by the valley margin setting in this window. The 1965 map is characteristic of large lateral bars and point bars, while the 2019 image has lateral bars, fairly smaller mid channel bars and a confluence bar.

The morphometric analysis of this window shows that the bar area has decreased by almost 25% between 1965 and 2019. The alluvial island area and main channel area have increased by 11% and 7% respectively. The tributary bars in 2019 have also reduced to 1/4th of their area in 1965. These observations suggest that flow in the Ganga river has been augmented in recent years and this is particularly visible downstream of its confluence with the Yamuna. Such flow augmentation is common at the confluence of large rivers and often result in incised channels. Both Ganga and Yamuna rivers have incised banks around Prayagraj which developed several thousands of years ago possibly during monsoonal intensification around early Holocene period.

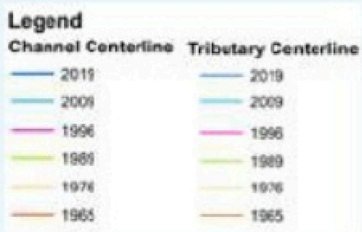


Geomorphic Class	1965 (area in sq.km)	2019 (area in sq. km)
Main Channel	11.4	12.68
Secondary Channel	0.9	0.96
Bars(Main channel)	55.86	41.54
Alluvial Island	15.02	16.14
Tributary channel	5.22	7.39
Bar (Tributary)	3.76	0.79

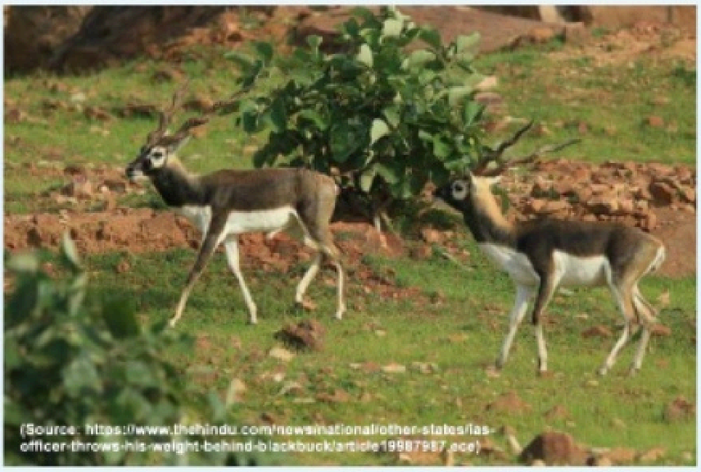
Riverine Environment



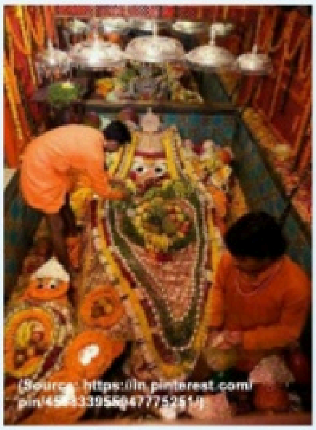
Magh mela, is an annual festival with fairs held in the month of Magha (January/February) near river banks and sacred tanks near Hindu temples.



The channel center line shift image of the six decades shows that the main channel of the Ganga River has been moderately migratory in this reach. The channel has migrated about 2.5 kms upstream of the Sangam region, and this has resulted in significant changes in the meander wavelength of the Ganga just before its confluence. Interestingly, the Yamuna river joining the Ganga at Prayagraj has been fairly stable in this window as its center lines for the respective decades do not show any significant migration between 1965 till 2019. This is primarily attributed to the highly incised channel of the Yamuna river before its confluence with the Ganga. The reaches downstream of the confluence have also been relatively stable and show only minor changes in the thalweg position between 1965-2019.

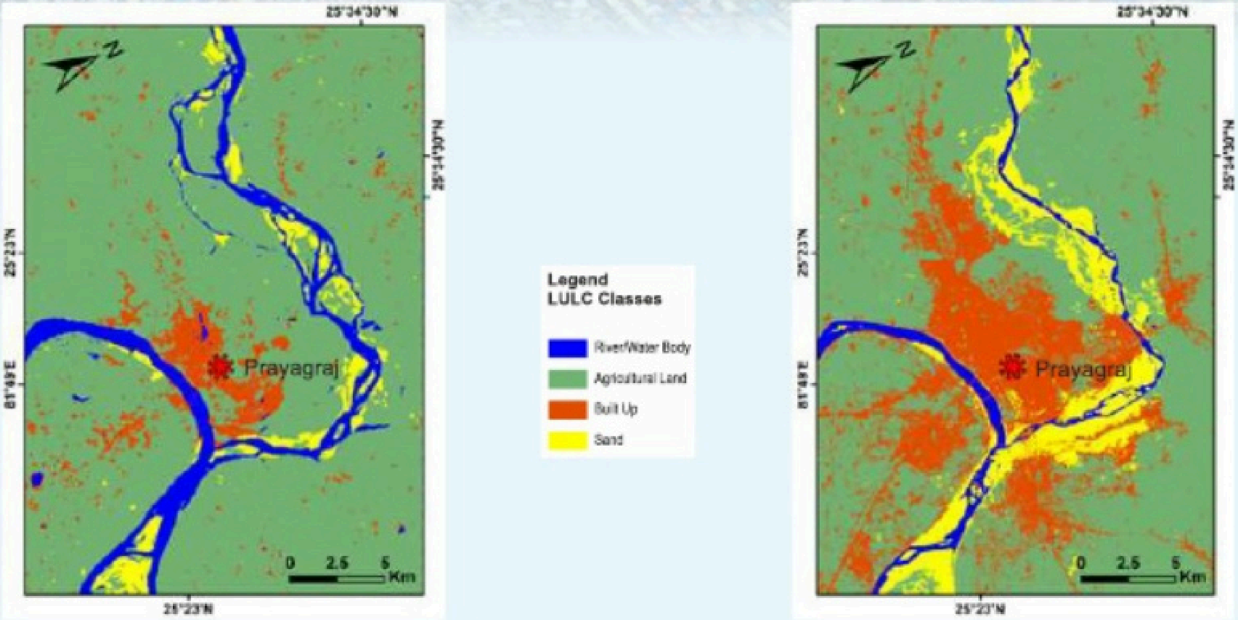


The State Cabinet has approved a Blackbuck Conservation Reserve in the Meja Forest Division, in the Trans-Yamuna region of Allahabad near the Madhya Pradesh border, known for its rocky, undulating and arid terrain. The conservation reserve will occupy 126 hectares.



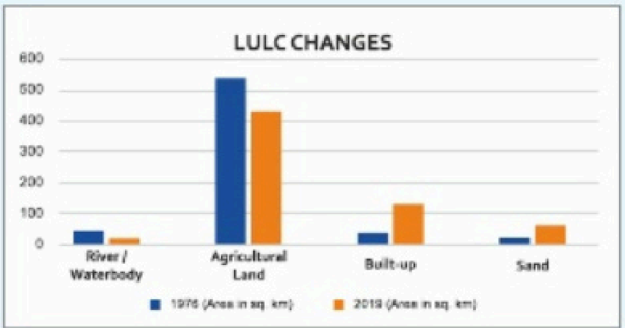
Allahabad is home to a beautiful Hanuman Temple with a 20-feet-tall statue of Lord Hanuman. This statue gets submerged in the waters of the river Ganga when it is in full flow. As per local legends, it is believed amongst Hindus that the river Ganga wants to touch the feet of Lord Hanuman, and hence it increases its water level.

Landuse and Landcover Changes



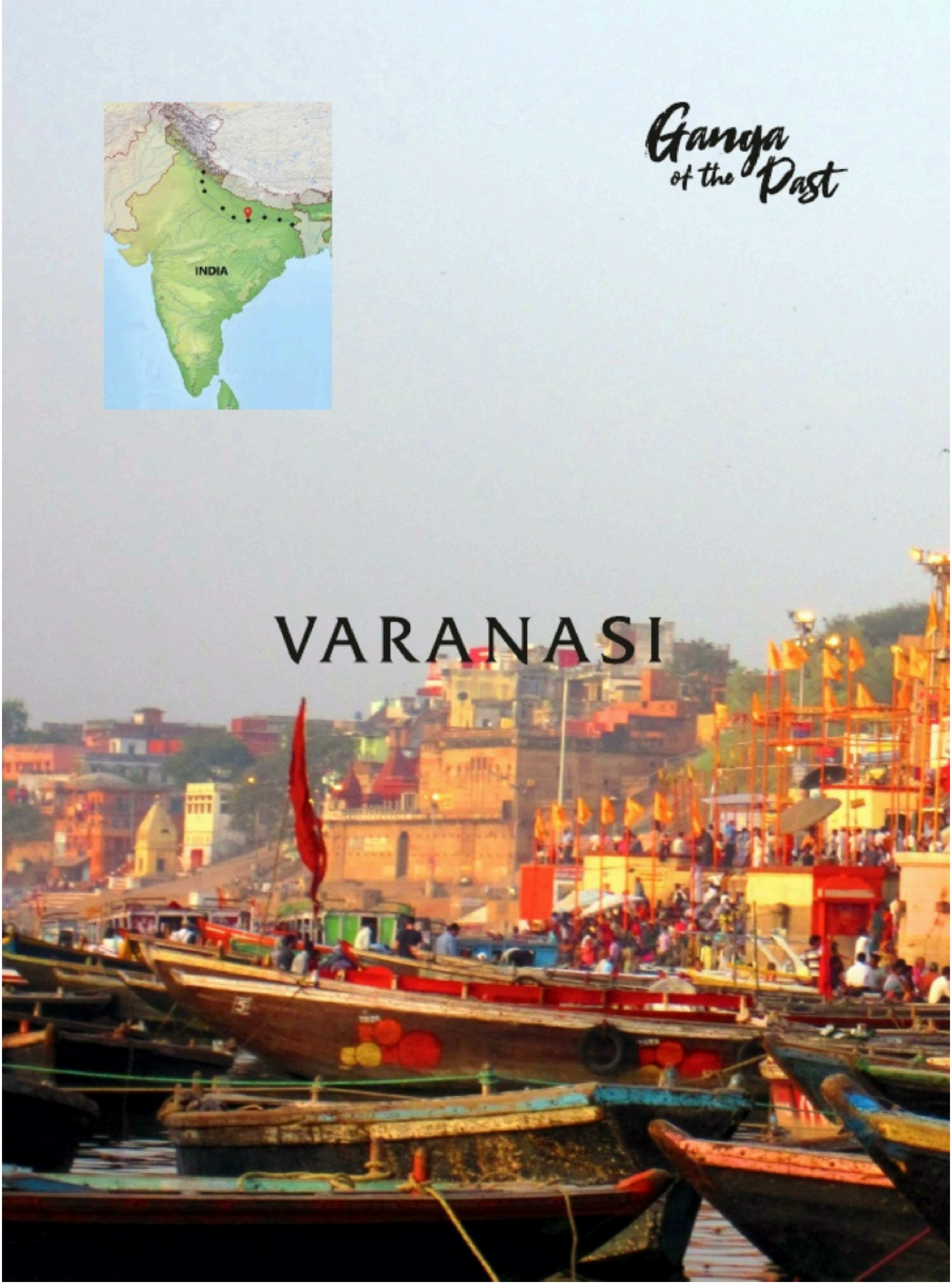
1976 **2018**

This window illustrates a rapid explosion in built up area due to urban expansion, by two hundred and fifty percent. The urban expansion has occurred both in the interchannel area between the Ganga and Yamuna and also towards the south east and south west of Prayagraj region. The area occupied by sand has increased by three-fold between 1976 and 2019. The area occupied by river/water body has decreased by more than fifty percent. The area occupied by agricultural land has decreased by twenty percent between 1976 and 2019.



LULC Classes	1976 (area in sq.km)	2019 (area in sq. km)
River/Waterbody	43.88	19.02
Agricultural Land	539.66	431.16
Built-up	36.87	130.34
Sand	20.81	60.99

Kumbh mela at Prayagraj in 1954 and 2019

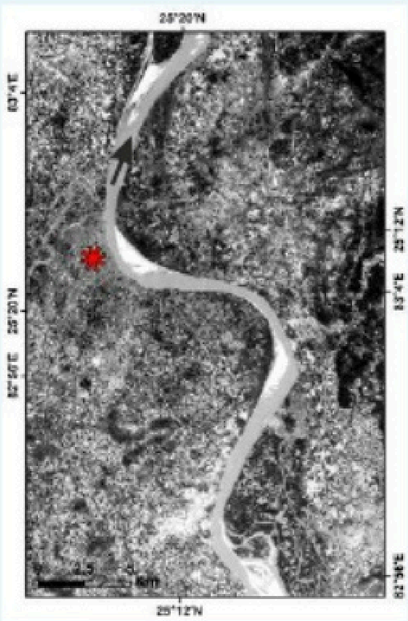


VARANASI

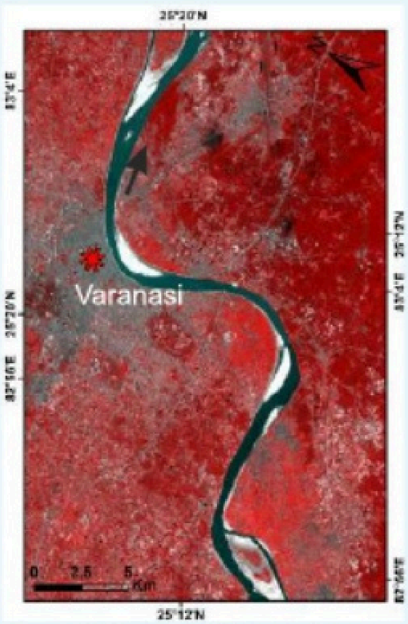
Geomorphic Setting

Ghats of Varanasi

Varanasi, also called **Benares, Banaras, or Kashi** is one of the world's oldest continually inhabited cities located on the left bank of the Ganges (Ganga) River. It is one of the seven sacred cities of Hinduism where pilgrims come to wash away sins in the sacred waters and to cremate their loved ones, hoping for liberation from the cycle of rebirth.



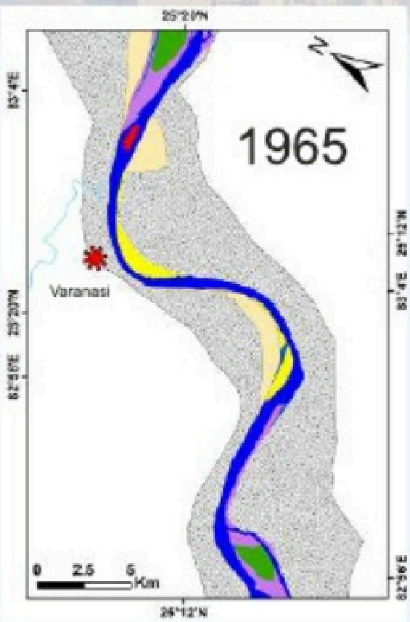
1965 Corona image

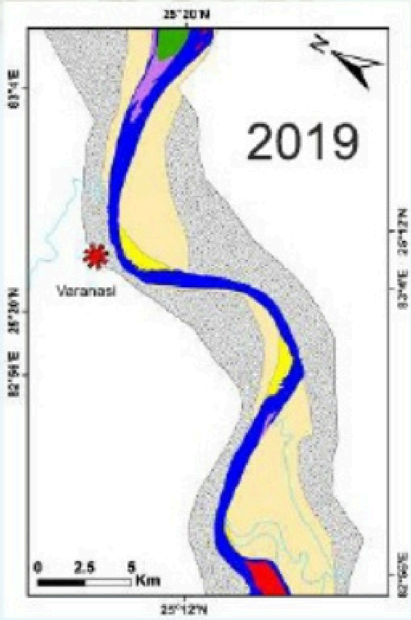


2018 Sentinel 2B FCC image

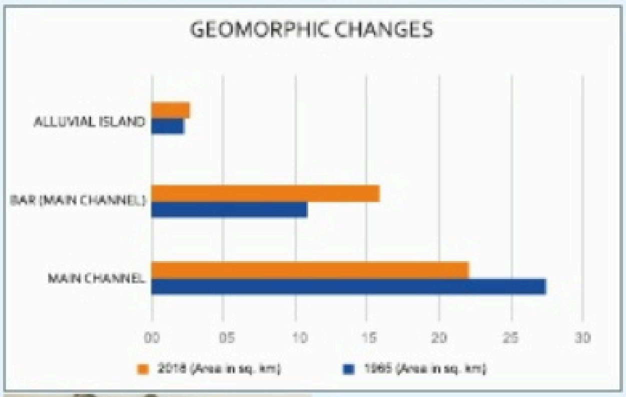
A comparison of the 1965 Corona and 2018 Sentinel images of the Ganga around Varanasi shows very little modification in channel morphology. In general, the channel has broad meanders in this reach and the position and form of the meanders are strikingly similar in both images suggesting a very stable reach. Not just the meanders, some of the large bars have also remained unchanged in more than 5 decades.

Channel Planform Changes



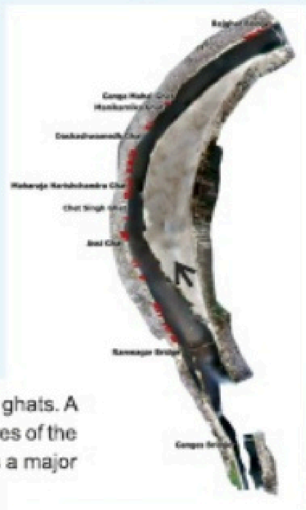


The channel belt of the Ganga River around Varanasi is unconfined in the valley margin setting. The river follows a sinuous path and is mostly stable with a few changes in the depositional landforms and main channel area. The 1965 image is characterized by large point bars, large mid channel bars and lateral bars, while the 2019 Sentinel image is characterized by large point bars, large lateral bars and small mid channel bars. Between 1965 and 2019, the depositional area manifested as bars have increased by almost thirty percent. The areal extent of the alluvial islands has increased by roughly fifteen percent. The main channel area has also decreased by twenty percent during this period. However, the overall channel pattern in this window has been fairly similar in this period. There is a notable increase in its active floodplain area between 1965 and 2019.



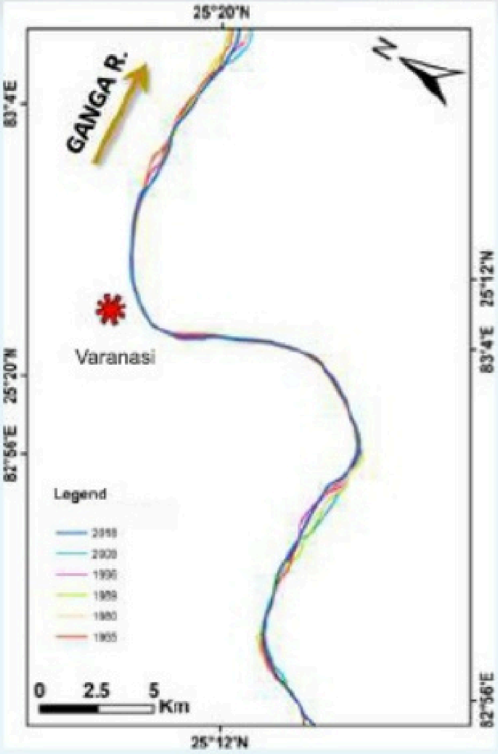
Geomorphic Class	1965 (area in sq.km)	2018 (area in sq. km)
Main Channel	27.49	22.14
Bar	10.89	15.56
Alluvial Island	2.27	2.7

https://www.wwfindia.org/?10185/118-Turtle-Hatchlings-Reunite-with-Ganga



A drone image of the Ganga around Varanasi (taken in march 2018) shows the positions of major ghats. A narrow channel and a large point bar on the right bank of the river are two most conspicuous features of the Ganga river at this location. Because of this stable morphology, this site was long maintained as a major turtle sanctuary since 1989 until it was de-notified in 2019.

Riverine Environment

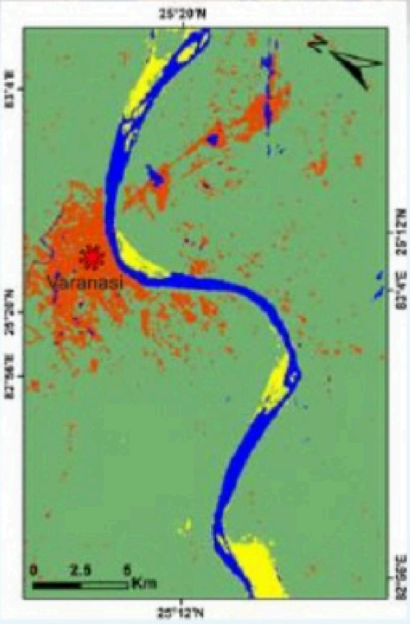


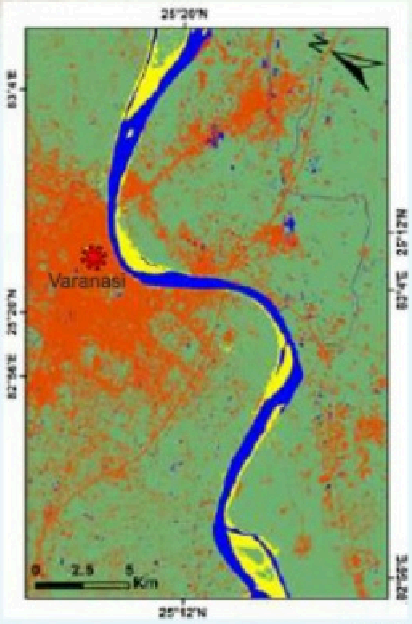
Channel Centreline shift in last six decades

The channel center line shift image of the six decades shows that the main channel of the Ganga River is fairly stable in this reach, with no evidence of channel migration. Some minor shifts of the sinuous bends are observed in certain reaches, indicating only small scale adjustments in channel form during the period 1965-2019. In several reaches, the river is backed by high cliffs as evidenced during site visits. These cliffs are composed of muddy sediments and have been fairly stable as manifested in dense vegetation cover and stablised slopes.

A view of the Ganga river at Varanasi expresses the tranquility of this site. Channel stability and sufficient water depth availability for most parts of the year makes this site an important tourist attraction in addition to the socio-cultural significance of Varanasi. Channel form and natural geomorphic setting of the Ganga River around this heritage site add enormous value and they must not be lost.

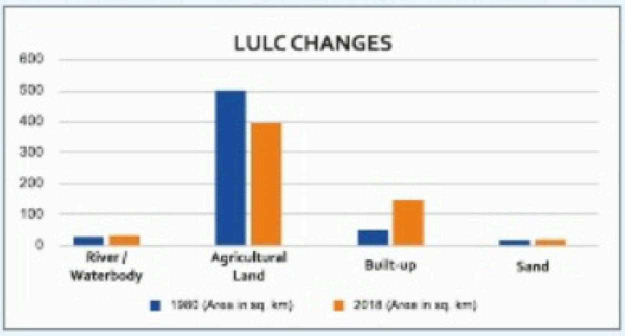
Landuse and Landcover Changes





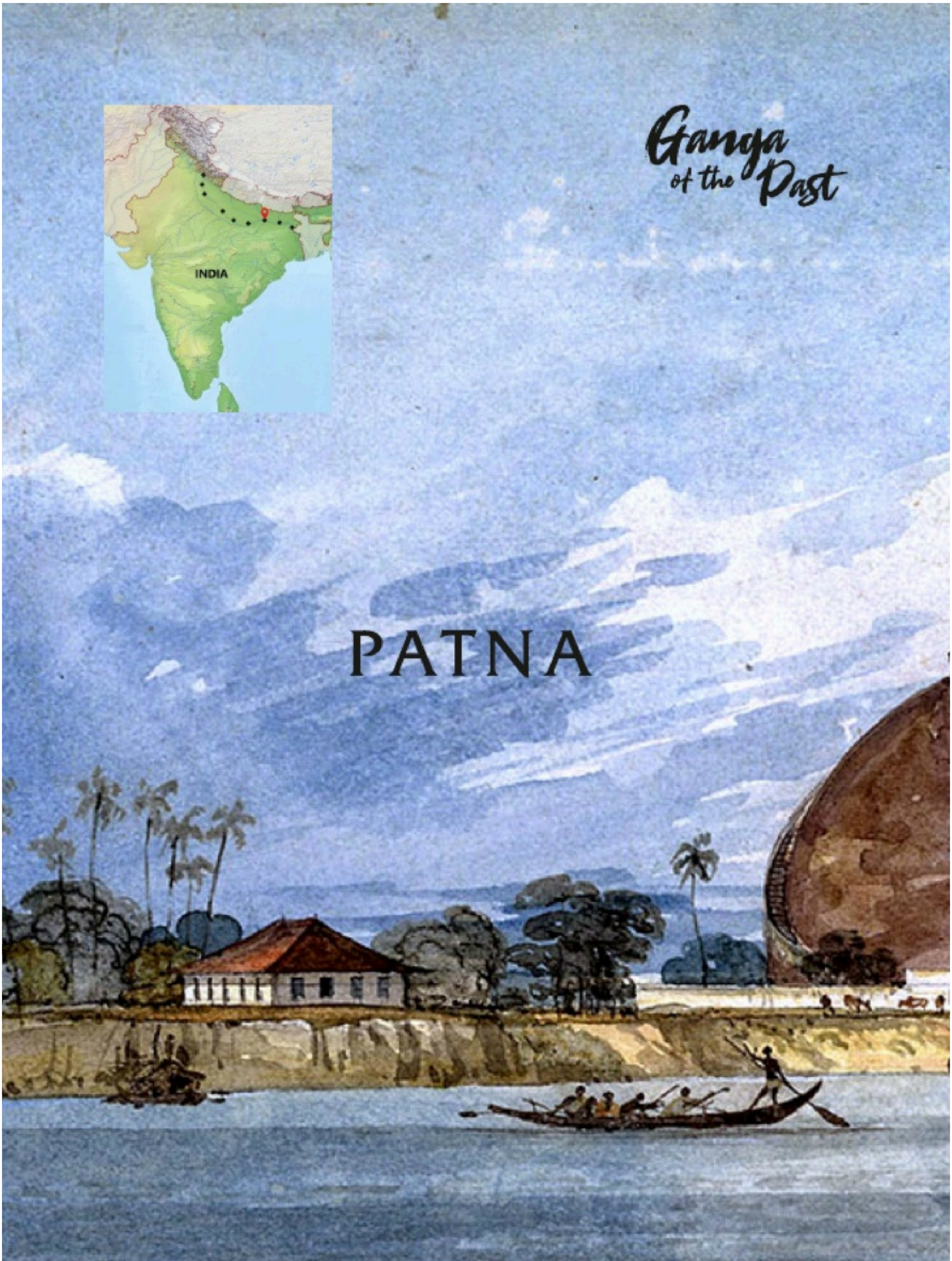
1980 **2018**

The city of Varanasi around the Ganga River has undergone an explosion in built up area - a two hundred percent increase is documented between 1980 and 2018 suggesting a rapid urban expansion. The urban expansion has occurred both in the north western and south western part of the Varanasi city and also towards south eastern portion towards the Mughal Sarai region. The area occupied by sand has increased by nineteen percent between 1980 and 2018. The area occupied by river/water body has increased by seventeen percent. The area occupied by agricultural land has decreased by 21% during this period.



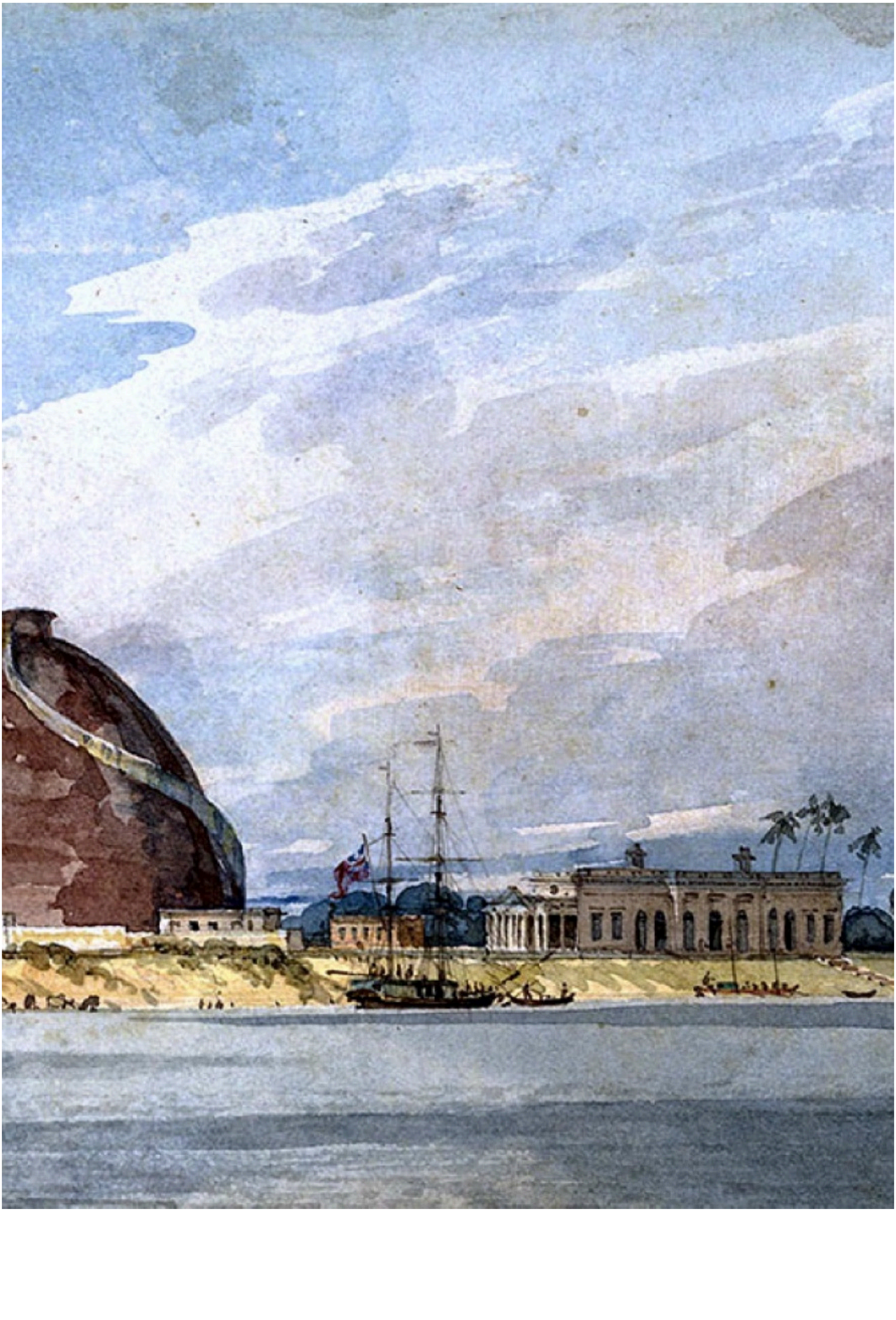
LULC Classes	1980 (area in sq.km)	2018 (area in sq. km)
River/Waterbody	26.02	30.48
Agricultural Land	501.24	396.26
Built-up	47.98	145.65
Sand	14.72	17.47

Because of the socio-cultural importance of Varanasi, the Ganga River around this site has received significant attention. The first phase of the Ganga Action Plan at Varanasi supported the organic removal of dead bodies by supporting the breeding and release of turtles in the river waters. The carnivorous turtles, would feed on the remains of the corpses and in turn help in reducing the organic and harmful wastes emanating from the corpses. Also, in the process, it would provide for food to the diminishing population of turtles and help them survive, grow, breed and increase their number. An associated development was the establishment of the Sarnath Turtle Breeding Center. Here, the eggs of the carnivorous specie of turtles are brought from the Chambal river and the new-borns are reared at the breeding centre under controlled conditions until they are mature enough to be released in the Ganges. Even though the new 30-km long Turtle sanctuary has now been shifted upstream of Varanasi (15 km downstream of Prayagraj), it is hoped that this important function of the turtles in maintaining the ecology of the Ganga will still be relevant in future.



Ganga of the Past

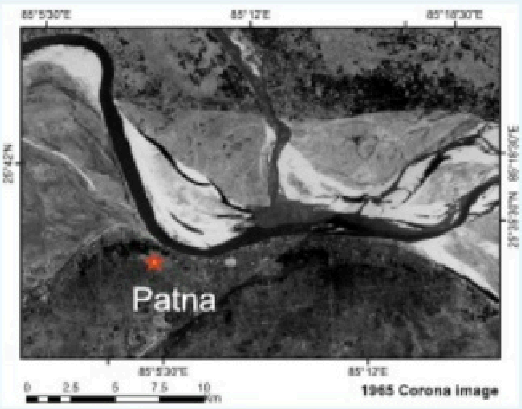
PATNA

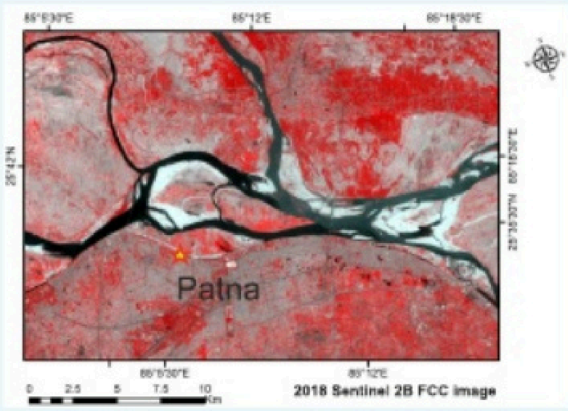


Geomorphic Setting

One of the oldest continuously inhabited places in the world, Patna, also known as Patliputra was the capital of the Magadh Empire. It was a seat of learning and fine arts and was home to many astronomers and scholars including Aryabhata and Chanakya.

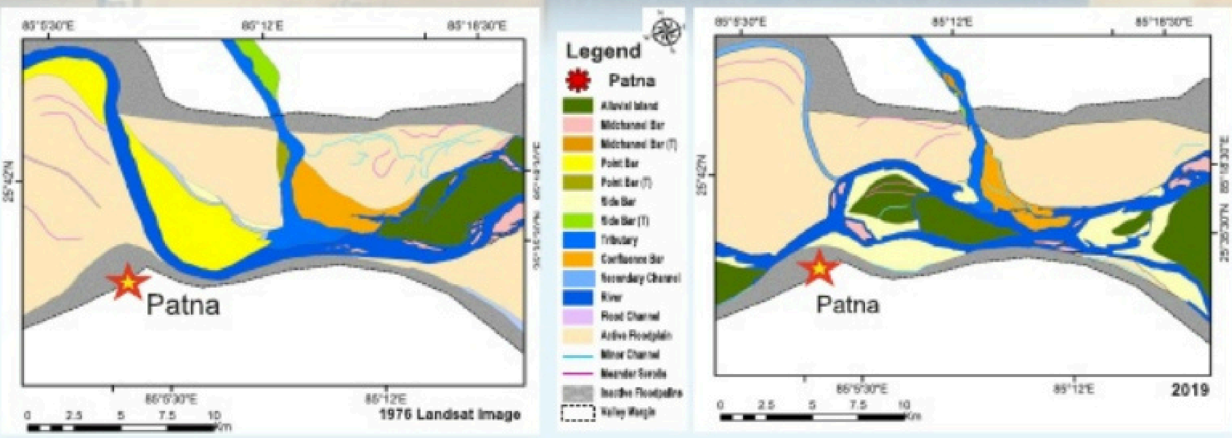
This window includes the confluence zone of the Ganga with another Himalayan river, the Gandak river draining from Nepal. The two rivers meet at Patna located along the right bank of the river. The course as well as the morphology of the Ganga river has changed remarkably between 1965 and 2018. A major intervention in this window is the Mahatma Gandhi Setu, the 4th longest bridge in India, constructed in 1982 connecting Patna and Hajipur.

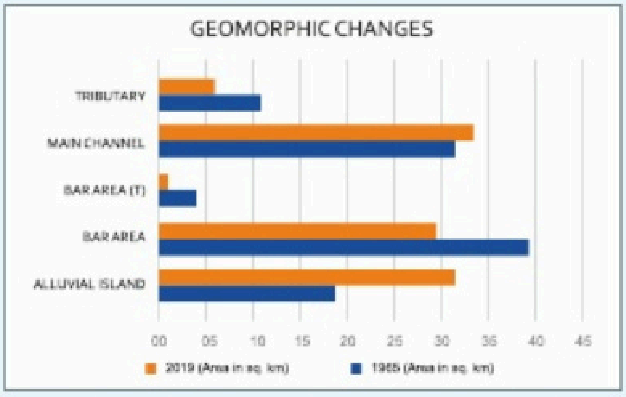




The nearly NNW trending single-channel course of the Ganga at Patna in 1965 changed to a E-W course and developed into an anabranched channel. A very large alluvial island has developed between the two anabranches. This island was earlier a part of the a large point bar but now lies within the channel belt - vegetated and stabilised. A comparison of the geomorphic maps for 1965 and 2018 reveals the transformation of planform features. The confluence point of the Ganga and Gandak has also moved northward and the confluence angle has also changed.

Channel Planform Changes



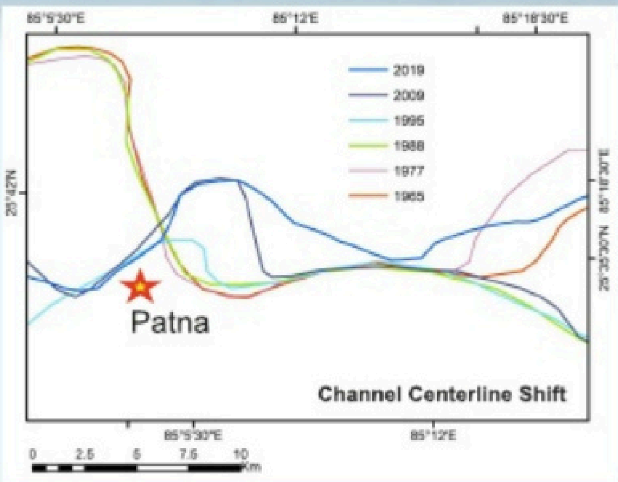


Geomorphic Class	1965 (area in sq.km)	2019 (area in sq. km)
Alluvial Island	19	32
Bar area	40	30
Bar Area (T)	4	1
Main Channel	32	34
Tributary	11	6

This window signifies a major aggradational zone because of a large sediment flux brought by the Gandak, and a significant increase in alluvial island area is noted. Such large scale sediment accumulation in the channel belt makes this reach a major 'hotspot of siltation - considered as one of the most serious problems in this stretch of the Ganga river. Morphometric data shows a reduction in bar area but a phenomenal increase in alluvial islands suggesting that several bars are now getting stablised and are vegetated or cultivated.

A drone image showing stablised alluvial island

Riverine Environment



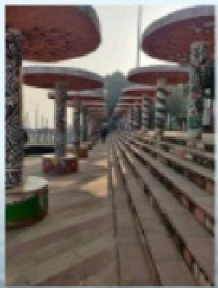
The Ganga River around Patna has been extremely dynamic in the historical time scale. The main channel has shifted by 5-10 km in several reaches between 1965 and 2019. The reconstruction of the channel dynamics shown (picture on the left) shows that the main channel of the Ganga was flowing very close to Patna city until 1995 but shifted northward in subsequent years forming a large meander loop. As shown in the geomorphic maps, the southern anabranch along the Patna city is much thinner and weaker. This has resulted in significant reduction in available flow and has also impacted the socio-cultural activities along the ghats all along the southern bank of the river. On the other hand, the areas along the northern bank are regularly inundated and the flood risk has increased manifold in this region.

Digha–Sonpur Rail-Road Bridge

2016 flood in Hajipur

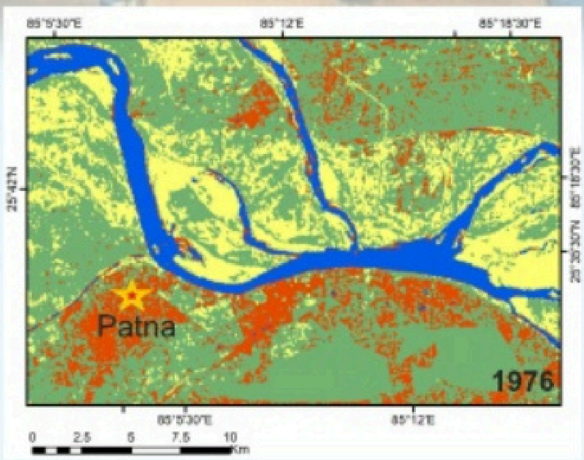
Riverfront development along the Ganga at Patna

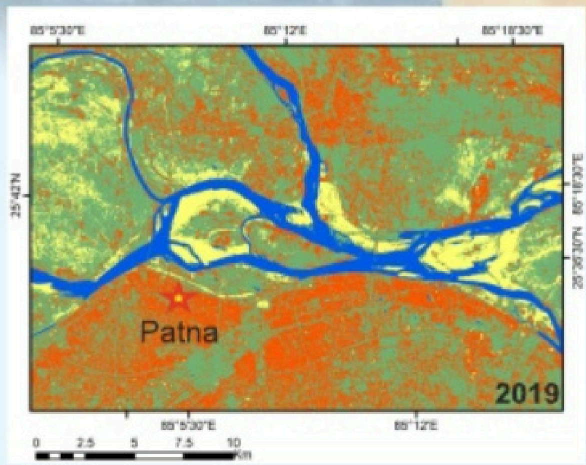
Rising water levels and inundation of alluvial islands around Patna



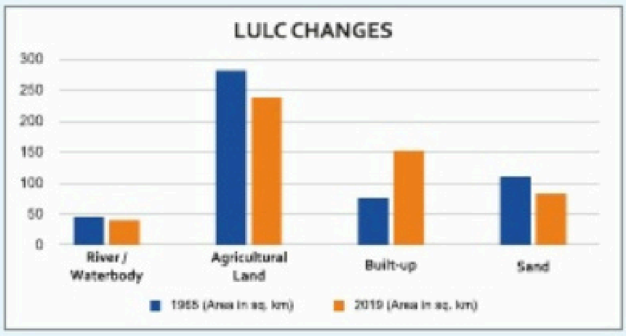
Several new and major interventions have come up in recent years. Upstream of the old Mahatma Gandhi Setu, a new Digha-Sonepur rail-road bridge has been constructed in 2016. A major river front development project has been undertaken under the Namami Gange program which entails a 5.7 km long walkway along the ghats. Another major project which is underway is to build a 20.5 km long elevated road, the Ganga pathway project. Such large scale projects are likely to cause significant morphodynamics in the Ganga river in this stretch and concerns have already been raised about likely siltation along the bank leading to shifting of the channel away from the ghats.

Landuse and Landcover Changes





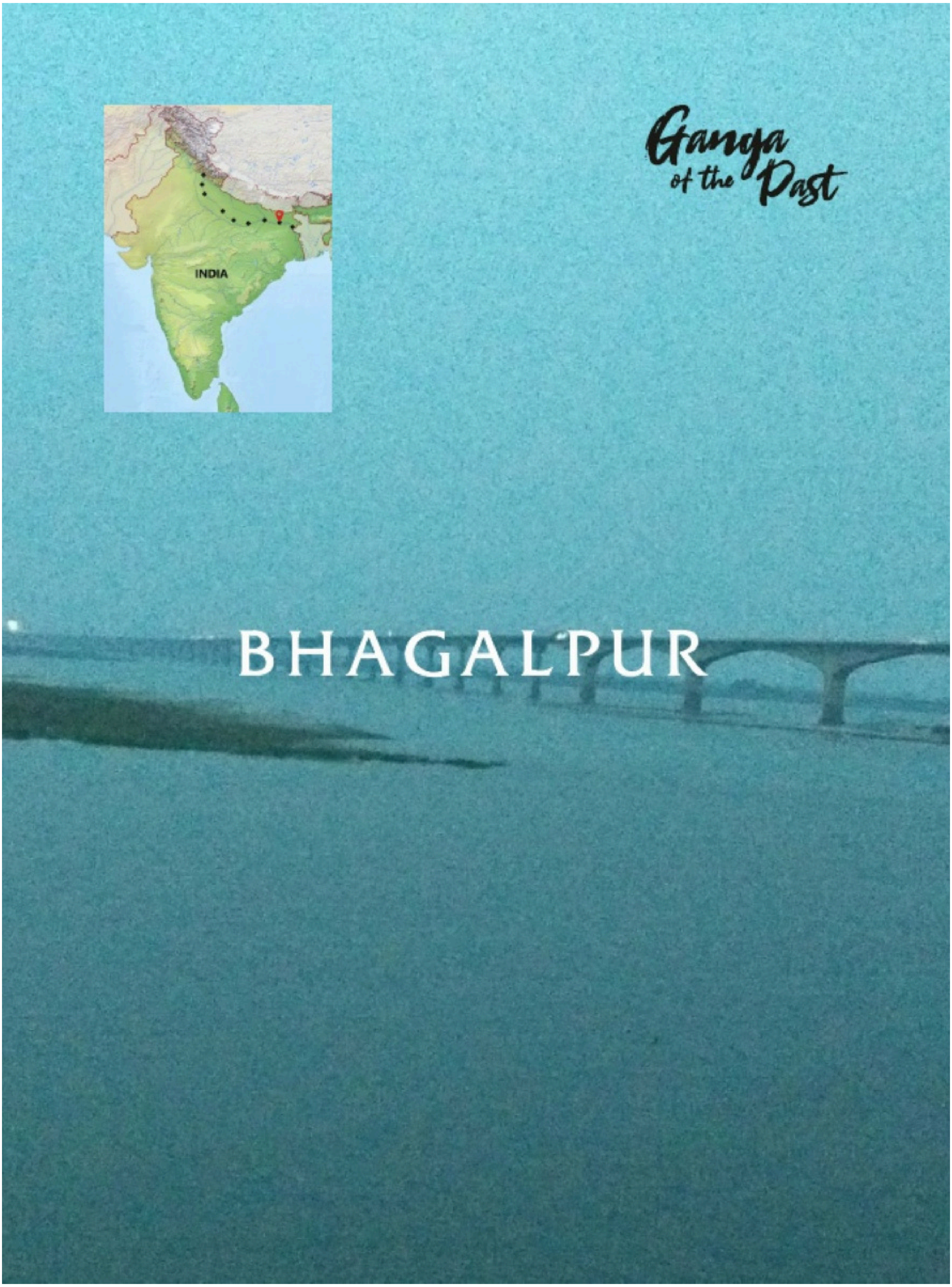
The phenomenal increase of the urban area along the right bank between 1976 and 2019 signifies the exponential growth of the Patna city in the last 4 decades. The other major landuse/landcover change which is easily noticeable is the transformation of the sandy patches north of the Ganga river to agricultural land and built-up area because of occupation of the active floodplain.



LULC Classes	1976 (area in sq.km)	2019 (area in sq. km)
Water Body	45	40
Agricultural Land	283	239
Built-up	76	153
Sand	111	83

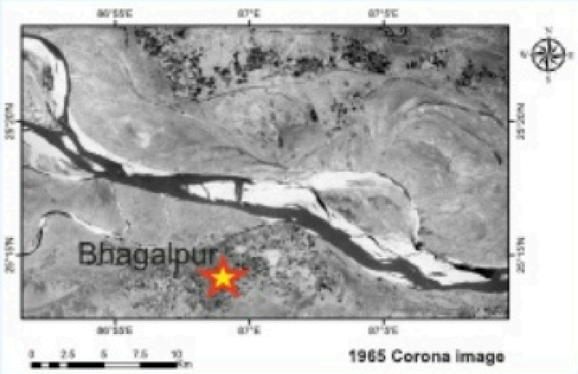
Drone image downstream of Patna shows the density of permanent and semi-permanent urban structures very close to the river which is not only changing the landuse but is also increasing the flood risk in this region. This calls for a proper river zoning policy.

Ganga of the Past

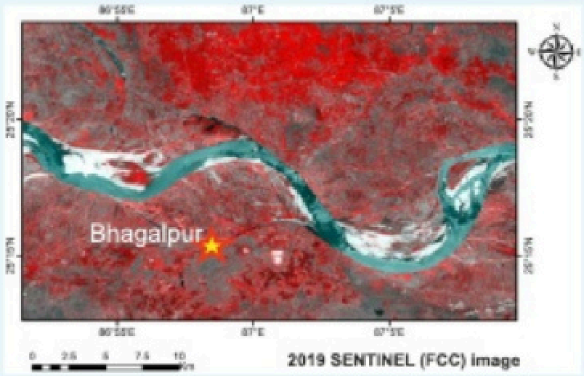


BHAGALPUR

Geomorphic Setting



1965 Corona image



2019 SENTINEL (FCC) image

The Ganga River flows in a nearly east-west direction in this window. The river has a moderately sinuous course and the sinuosity has increased between 1965 and 2019. The river has a multi-channel morphology but the flow in the anabranches has changed significantly through time as we compare the 1965 and 2019 images. Large meanders, particularly on the northern side, vouch for the highly dynamic regime of the river in the past.

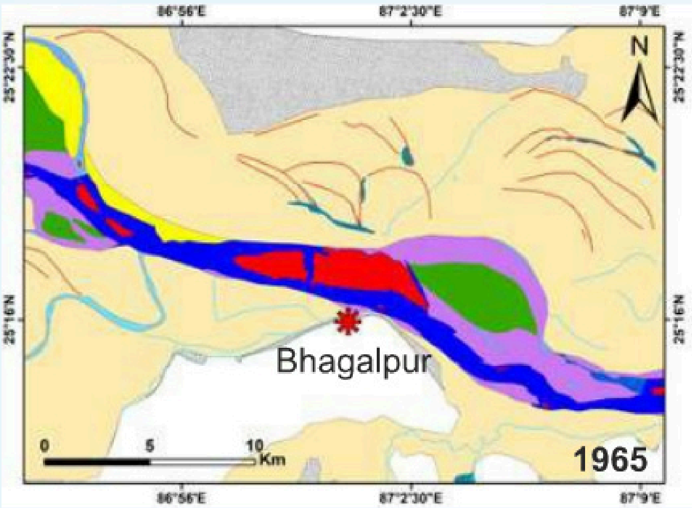
Bhagalpur is an old town situated in eastern Bihar on the fertile banks of the Ganga River. It has been associated with the silk industry for hundreds of years, and famous for Tussar Silk & Bhagalpuri

Saree. Silkworms are employed to produce the renowned Tussar Silk from which Tussar Saree is manufactured. The Silk Institute and Agricultural University are located in the city.

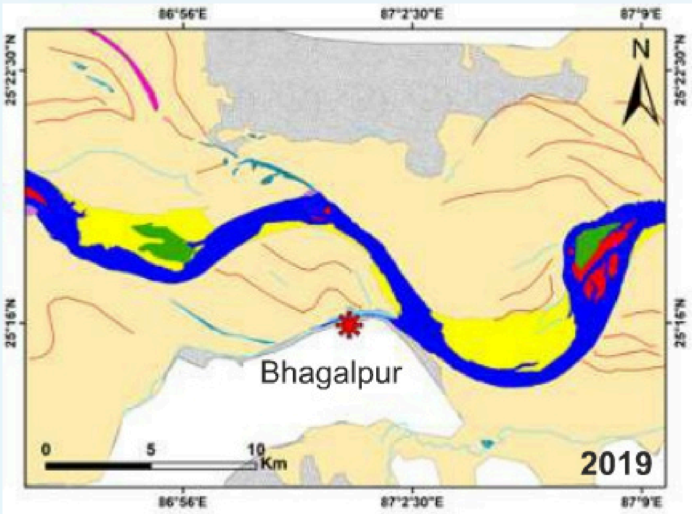
Vikramshila Setu is a 4.7 km long bridge built across the Ganga River around Bhagalpur named after Vikramshila University, an ancient seat of learning. It is the third longest bridge in India and connects NH 80 and NH 31 which run parallel on the opposite sides of the Ganges. The bridge lies in the reaches of river notified as the Vikramshila Gangetic Dolphin Sanctuary and rare Gangetic dolphins can be spotted in the area.

Low lying banks of the Ganga river around Bhagalpur are protected by embankments and spurs. Large scale siltation in the channel makes the adjoining banks prone to flood during the monsoon period.

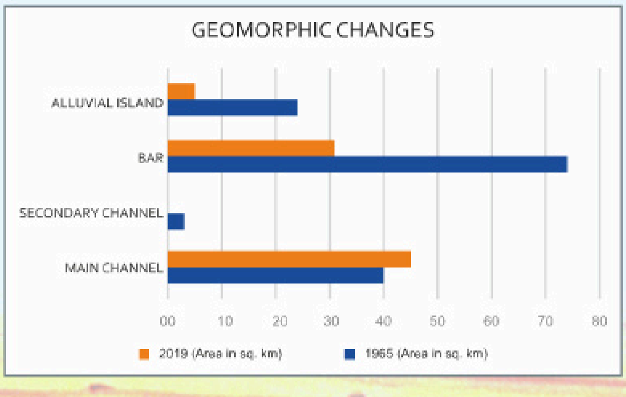
Channel Planform Changes



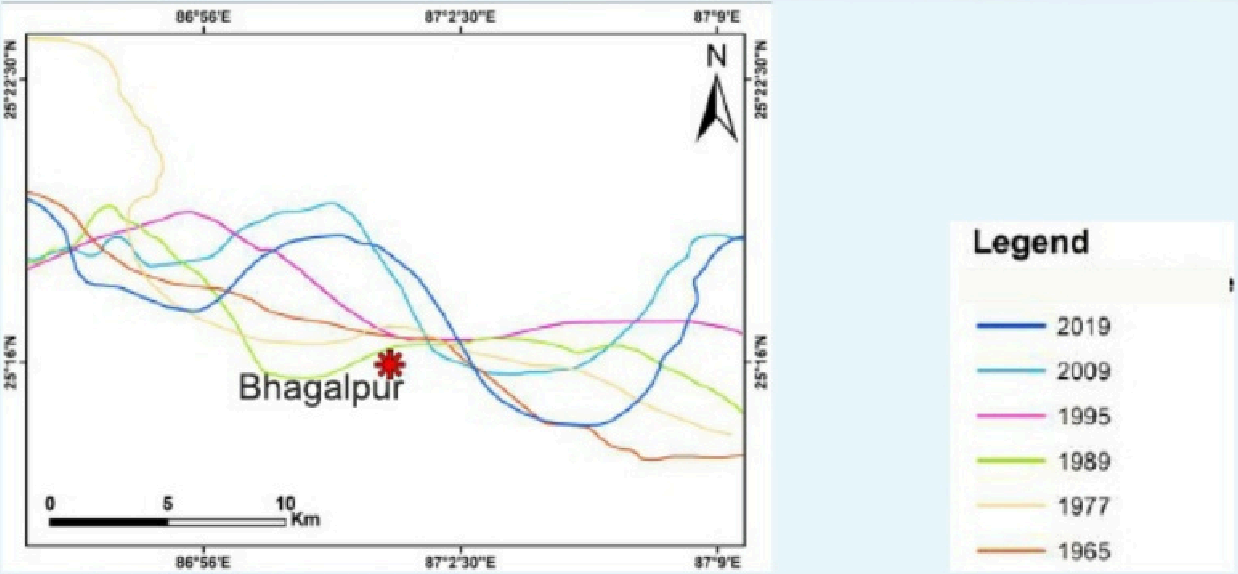
The morphology of the Ganga River around Bhagalpur has changed significantly between 1965 and 2019 - the most obvious is the increase in sinuosity and reduction in channel multiplicity immediately north of Bhagalpur city. A dominantly single channel flow is now confined within the banks but the channel becomes highly braided in the downstream reaches. However, the disappearance of large alluvial islands and mid-channel bars during this period is particularly noted, and this seems to suggest that the channel has become deeper. The prominent alluvial islands in 1965 have now become a part of the floodplain.



The modern active floodplain of the river in this stretch shows several meander scars, marshy/ wetlands and minor channels, signifying good lateral connectivity of the river in this stretch.

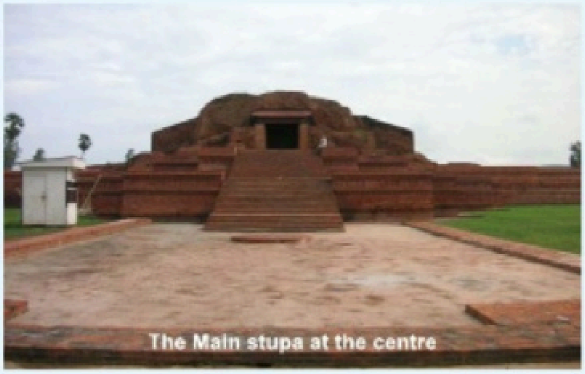


Geomorphic Class	1965 (area in sq.km)	2019 (area in sq. km)
Main Channel	40	45
Secondary Channel	3	0
Bar	74	31
Alluvial	24	5



Channel Centreline shift in last six decades

The centerline of the Ganga River mapped from successive satellite image shows significant movement of the channel during the last six decades. From a nearly straight course in 1965, the centerline has not only been wandering but has also become more and more sinuous. It is interesting to see that the river was literally touching the Bhagalpur city in 1988, but currently flows more than 5 kms away from the city.



The Main stupa at the centre

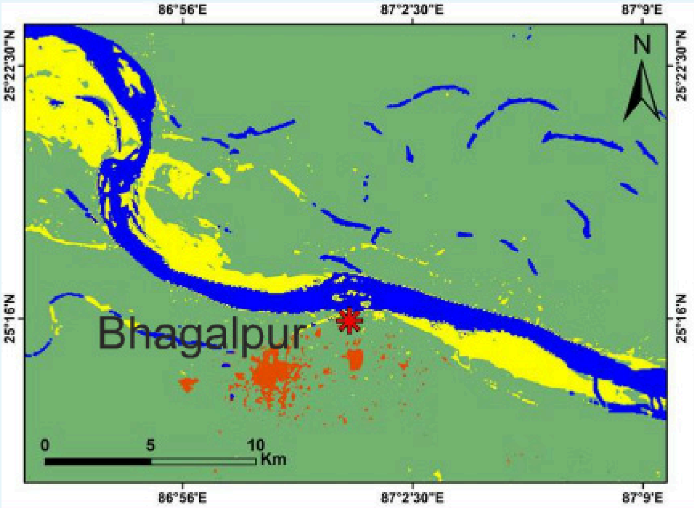
The seating and meditation area

Vikramashila Ruins: The Royal university of Vikramshila, 38 km from Bhagalpur

(Source:https://www.telegraphindia.com/state

Vikramshila Gangetic Dolphin Sanctuary's is a 50 km stretch of area situated on river Ganga. The major attraction in this area is the Gangetic Dolphins (Soons) which have been declared as endangered species. The Sanctuary also provides a safe abode to a rich diversity of other threatened aquatic wildlife such as freshwater turtles and 135 other species.

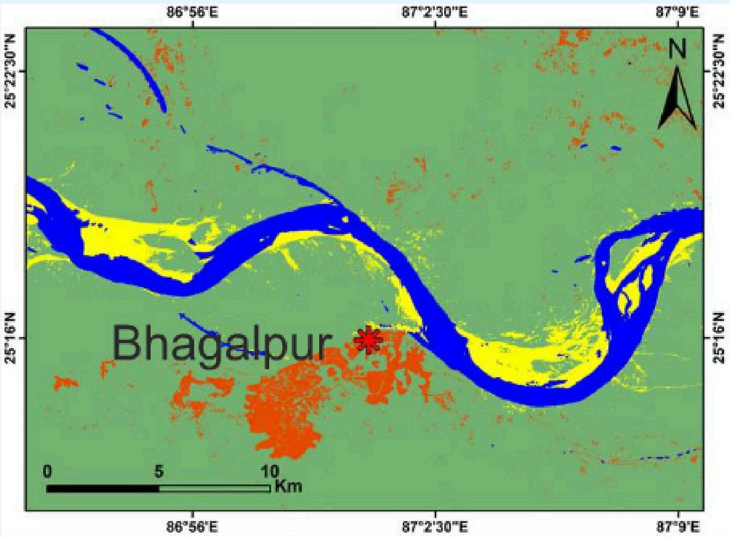
Landuse and Landcover Changes



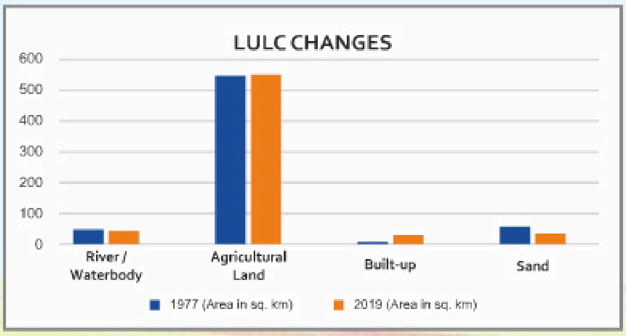
1977 Landsat Image

The landuse and land cover along the Ganga River around Bhagalpur show moderate changes over a period of ~40 years (1977-2019) as depicted in the maps and table. The most remarkable change is the reduction of sandy bars along the river from ~52 sq.km. to ~20 sq.km., most of which have been converted into agricultural land and built up area. An increase in the built up area from ~7 sq. km. to ~30 sq.km. clearly suggests the population expansion in and around the city.

From the 2019 image it can be observed that the built-up area has increased more towards the south western part of the Bhagalpur town. Agricultural intensification can also be observed on the depositional sand bodies in the recent imagery. The changes in landuse and landcover, particularly of the sandy areas, relate to river dynamics. As the river meander shifts, the point bars merge into the floodplain and then converted into built up areas or agricultural land.

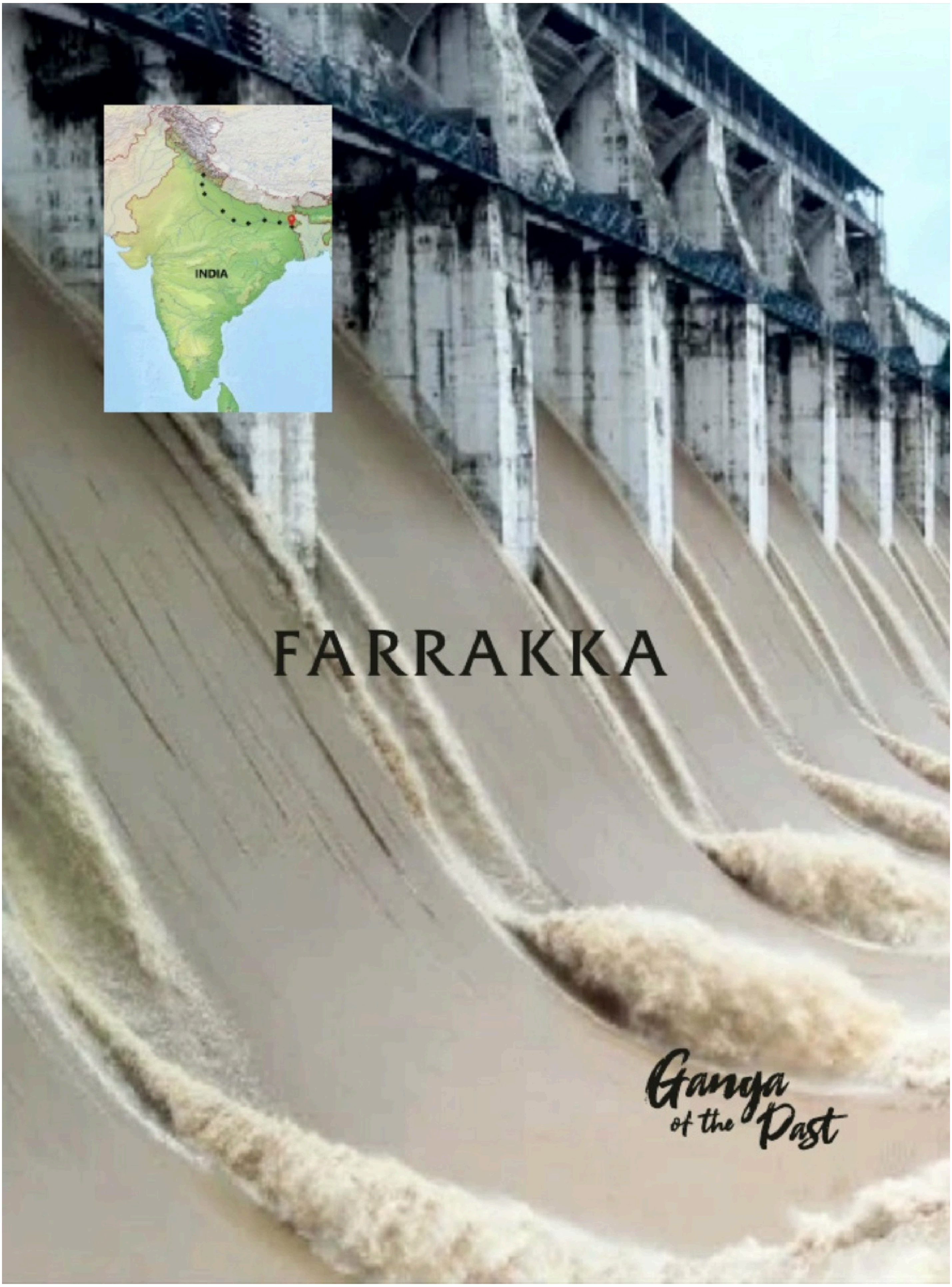


2019 Sentinel Image

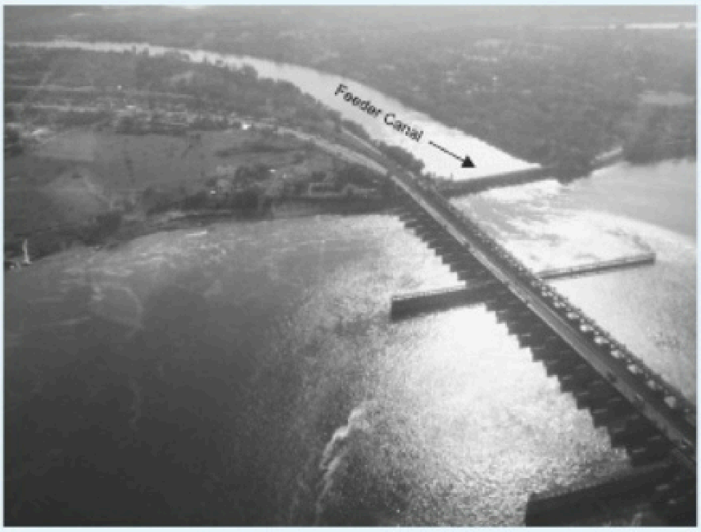


LULC Class	1977 (area in sq.km)	2019 (area in sq. km)
River/ Water body	48	44
Agricultural Land	548	552
Built-up	7	29
Sand	57	35

FARRAKKA



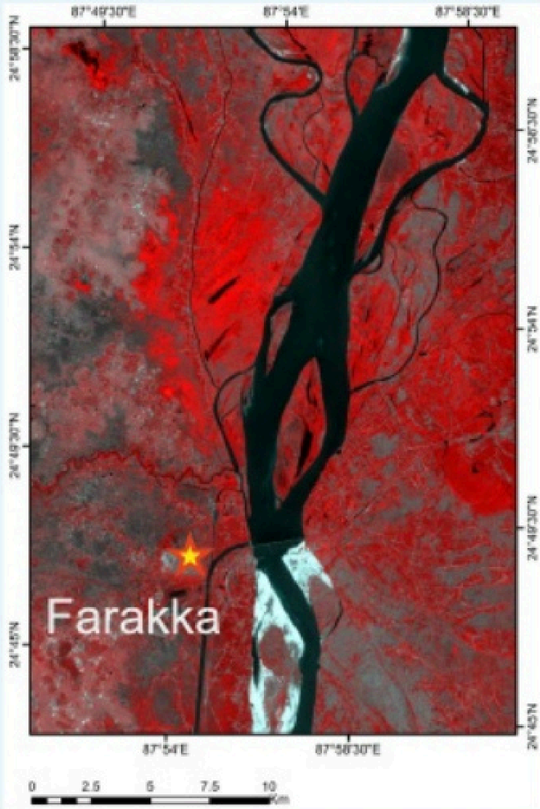
Geomorphic Setting



A major engineering intervention in the form of the Farakka barrage constructed in 1975 dominates the landscape here. The main objective of the Farakka Barrage Project was envisaged as diversion of adequate quantity of Ganga waters to Bhagirathi-Hoogly river system to maintain the Kolkata Port. For this, a 38.38 km long feeder canal was constructed. In addition, a rail-cum-road bridge was also built across the river Ganga at Farakka to establish the direct link to the North-Eastern Region with rest of the country.

Farakka Barrage across the Ganges river is roughly 16.5 kilometres from the border with Bangladesh. The barrage is about 2,240 metres long and the Feeder Canal (Farakka) from the barrage to the Bhagirathi-Hooghly River is about 40 km long.

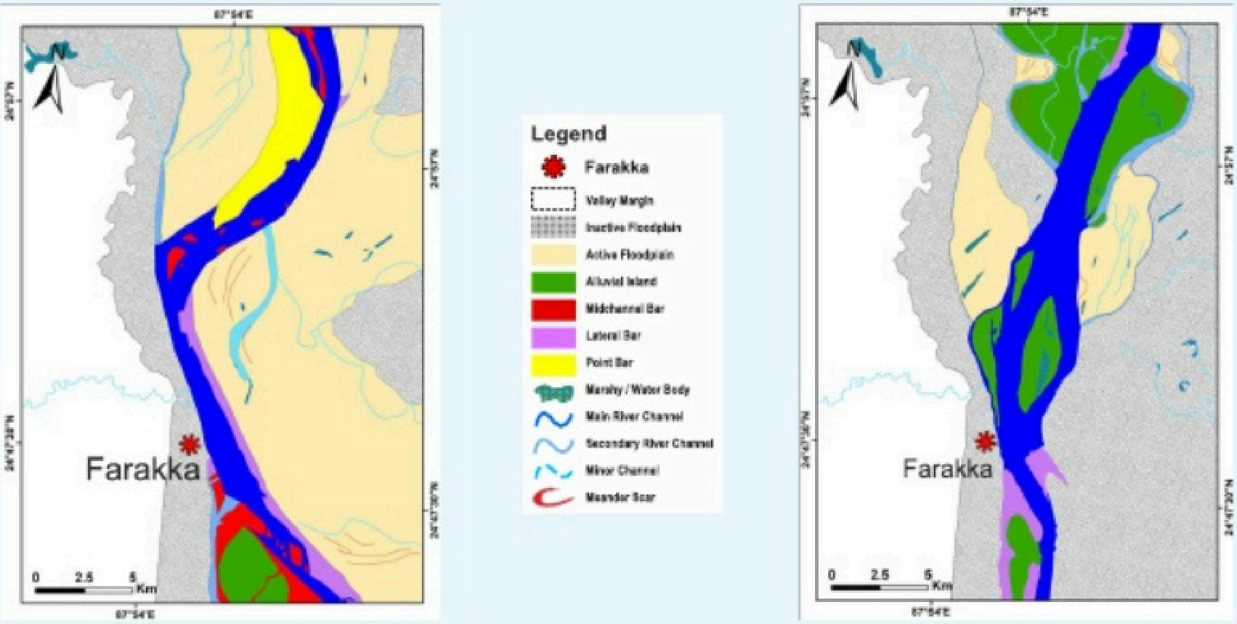
1965 Corona image



2019 Sentinel 2B FCC image

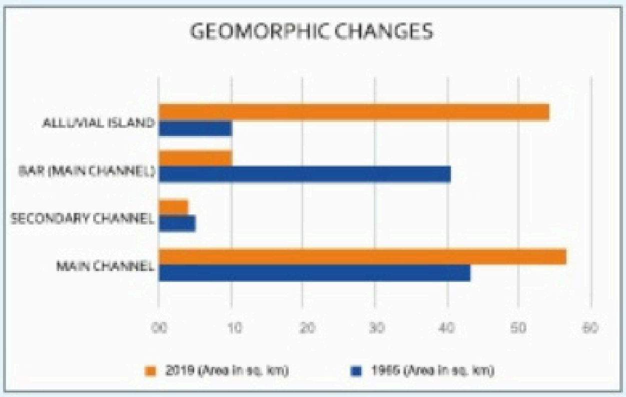
The Farakka barrage has imposed a significant transformation on the morphology of the Ganga river as illustrated by the Corona image of 1965 and a recent sentinel image taken in 2019. The 1965 image nearly corresponds to the period when the construction of the barrage had just begun in 1961 and some minor modification due to embankments are visible already. The 2019 image shows a complete transformation of the river and the mophological changes are shown on the next page.

Channel Planform Changes



1965 2019

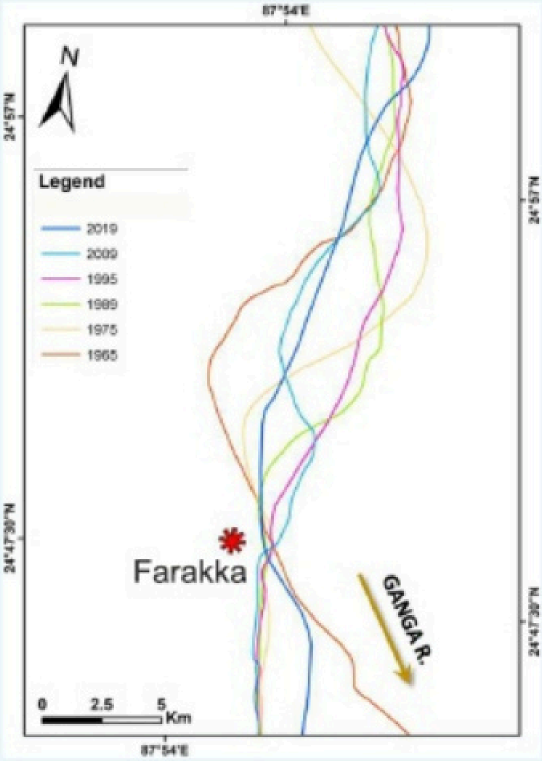
The planform map produced from the 1965 Corona image is marked by a highly sinuous channel in the upstream section but a nearly straight channel in the middle segment which is clearly a manifestation of channel confinement because of the embankment construction. The most downstream reaches show deposition of large point bars, side bars and mid channel bars. The 2019 planform map shows a very contrasting morphology after ~40 years of the barrage construction. A large alluvial island upstream of the Farakka barrage is conspicuous along with several others further upstream. The channel is clearly divided into multiple branches and channel widths have significantly changed both upstream and downstream of the barrage. A significant reduction in the active floodplain width is particularly noted which is a manifestation of controlled flow through the barrage.



Geomorphic Class	1965 (area in sq.km)	2019 (area in sq. km)
Main Channel	43.34	56.85
Secondary Channel	5.11	4.05
Bar	40.65	10.21
Alluvial Island	10.04	54.41

The morphometric data generated for from the planform maps of 1965 and 2019 illustrate the moprhodynamics induced by the barrage further. The alluvial islands have increased by five folds, between 1965 and 2019. The in-channel depositional area manifested as bar area has decreased four folds by 2019, with deposition of mostly lateral bars. Significant channel widening particularly in the reaches upstream of the barrage is manifested in an increase in the main channel area from ~43 sq.km in 1965 to ~57 sq km in 2019.

Riverine Environment



Graph showing thalweg shift

The reaches upstream of the Farakka barrage have been fairly dynamic since the construction of the barrage as manifested in the channel center line shift during the six decades. A fairly sinuous pattern is observed in 1965. Since then the center line has shifted enormously to the east as well as west particularly in the 10-15 km stretch upstream of the barrage. Between 1965 and 2019, the thalweg sinuosity upstream of the barrage has also changed significantly, the 2019 course being nearly straight.

Ganga river cruises from Farakka to Patna and Kolkata

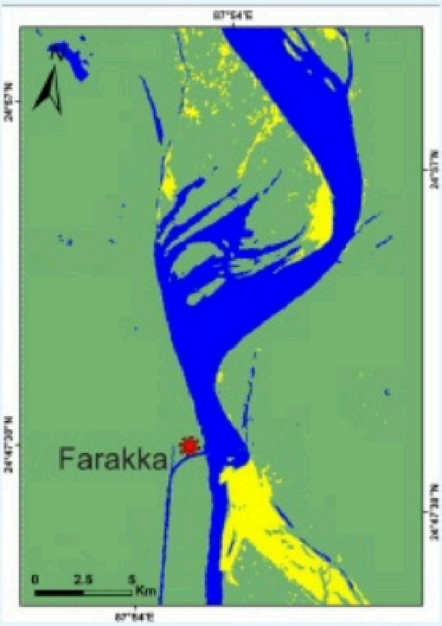
The Farakka barrage has a total of 108 gates that are used to divert water from the Ganga to Bangladesh under the Ganga Water Treaty (GWT). It also has 4 additional fish lock gates and 11 head regulator gates for diverting 40.000 cusecs of water into the feeder canal.

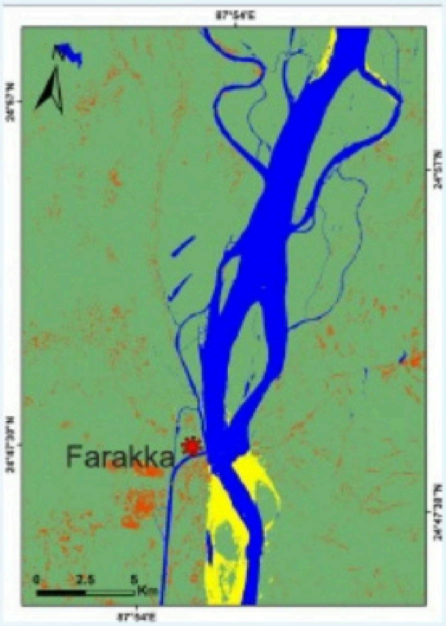
View of the Farakka barrage from Farakka bridge.

The role of the Farakka barrage on the river morphodynamics has been hotly debated. One of the major impacts of the barrage has been siltation of the channel bed upstream of the barrage (see next page) which has in turn influenced the channel morphology. The channel downstream therefore gets depleted of sediments and is known to have caused significant erosion in the downstream reaches as well as sediment starvation in the Ganga-Brahmaputra delta.

Severe bank erosion along the Ganga river downstream of the Farakka barrage at Manikchak.

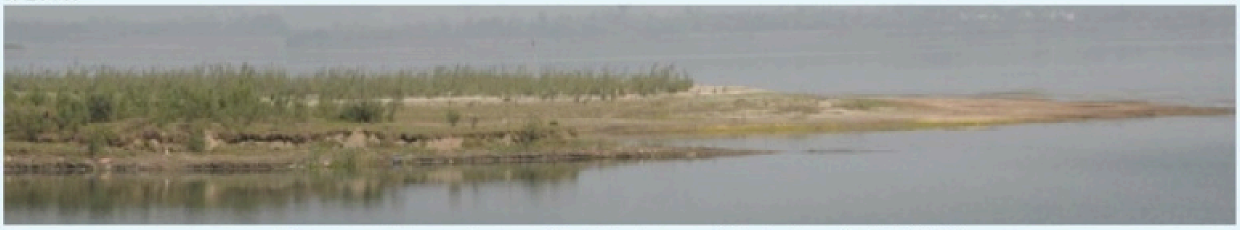
Landuse and Landcover Changes



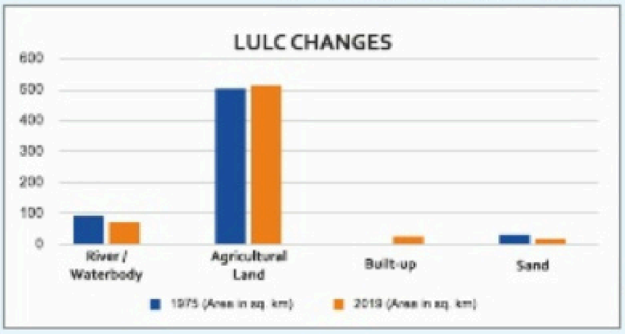


1975 **2019**

Significant changes in landuse and land cover are noted around Farakka between 1975 and 2019. The built-up area was almost negligible in this window until 1975 but currently occupies 23 km^2 of area. The area occupied by agricultural land has remained more or less constant, with only a minor increase. The area denoting sand deposition has decreased by more than fifty percent between 1975 to 2019.



A large sand bar upstream of Farakka barrage (Photo taken in Feb 2018)



LULC Classes	1975 (area in sq.km)	2019 (area in sq. km)
River/Waterbody	90.76	69.26
Agricultural Land	504.55	517.499
Built-up	0	23.13
Sand	28	13.44

Farakka Port or Farakka Floating Terminal is one of the minor river ports in West Bengal. It is located near Farakka town of Murshidabad district. Mainly coal is brought from Indonesia to this port.

(Source:https://commons.wikimedia.org/wiki/File:Farakka_Port@.png#file)

Epilogue

This project has successfully demonstrated the use of the historical satellite images such as the Corona for understanding the geomorphic as well as human-induced changes in river form and processes. This Atlas has attempted to capture the major changes in the Ganga River in a few selected windows based on their geomorphic as well as socio-cultural importance. We have interpreted and compared the Corona images with the recent Landsat images to derive information about the geomorphological changes and anthropogenic impacts on the river Ganga. The length of the Ganga river between Haridwar and Farakka is now covered by the archival imagery with ± 20m positional accuracy. In all we processed a total of 79 Corona images as a part of this project and these corrected images will be put in the public domain for the use of the scientific community. There are still several technical challenges in using the Corona images to their full potential and we will continue our research to refine the methodology for achieving better accuracy and reducing the processing time.

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