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Adi Ganga: The Living Aquifer of South Kolkata

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River Continuity, Groundwater Security, Ecological Balance and the Sustainability of an Urban Metropolis

A Geo-Environmental Assessment of the Consequences of Flow Regulation, Barrage Construction and River Modification

Abstract
Adi Ganga, a historic Hooghly distributary, is a severely degraded yet vital hydro-ecological corridor of South Kolkata. Major Tolly opened Tolly's Nullah in 1777 through its nearly dead channel for navigation and drainage, extending 27.2 km toward the Bidyadhari system at Samukpota. Further dam, barrage or restrictive modification could disrupt hydro-geomorphological equilibrium, altering flow, water levels, sediment transport, tidal exchange, groundwater interaction, flood conveyance and pollutant retention, thereby affecting groundwater quality, waterlogging, soil moisture and potentially subsidence vulnerability. Studies link surface pollution with groundwater degradation, while NGT promotes restoration. Therefore, EIA, groundwater modelling, sediment, flood and ecological assessments should precede intervention, prioritizing ecological flow and restoration.

Keywords: *Adi Ganga, Tolly's Nullah, South Kolkata, groundwater, hydrogeology, ecological balance, urban river, land subsidence, flood management, barrage, sustainability, geo-environment.*

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I. Introduction

Kolkata is a riverine metropolis whose geographical identity has been shaped by the Ganga-Bhagirathi-Hooghly river system, tidal channels, wetlands, floodplains, canals and innumerable drainage networks. The southern part of the metropolis has historically been connected with the Adi Ganga, an ancient channel associated with the Hooghly system.

The Adi Ganga is not merely a watercourse visible on a map. It represents a complex hydrological, geomorphological, ecological, cultural and socio-economic system. Its historical transformation from an important river channel into Tolly's Nullah and subsequently into a heavily polluted urban watercourse reflects the broader history of Kolkata's urbanization.

The West Bengal Irrigation and Waterways Department records that Major Tolly utilized the bed of the almost-dead Adi Ganga and opened the Tolly's Nullah in 1777 as part of the historical drainage and navigation system. The channel ultimately connected towards the Bidyadhari system.

The contemporary challenge is therefore not simply to "clean a drain." It is to determine how the remaining river corridor contributes to the environmental functioning of South Kolkata and how its future modification may affect the city's sustainability.

One particularly important question is whether the construction of a dam or barrage across Adi Ganga could create long-term environmental consequences.

The answer requires an integrated geo-environmental approach.

II. Objectives of the Study

The principal objectives are:

1.1. To examine the geographical and historical importance of Adi Ganga.
1.2. To analyze its role in the hydro-ecological system of South Kolkata.

1.3. To examine the relationship between Adi Ganga surface water and adjoining groundwater.
1.4. To understand the possible consequences of constructing a dam or barrage.
1.5. To examine the relationship between river modification, drainage and urban flooding.
1.6. To assess possible implications for soil-water conditions and land stability.
1.7. To distinguish classical geological isostasy from local hydro-geotechnical equilibrium.
1.8. To propose a sustainable management framework for Adi Ganga.

III. Methodology

Morpho-dynamics of the city is changing rapidly to analyze these problems I have adopted threefold methodology, these are

3.1 Pre-field Methodology:

Before going to the field, I have collected various information regarding the problems of the city Kolkata and at the same time I had also collected various data and information regarding the changing nature of the city along with Adi Ganga and its Morpho dynamics. Various other organization and websites for the collection of data and information regarding the morpho dynamics of Kolkata are as follows:
Extracted Satellite images and DEM from Google Earth Engine NBSS (National Bureau of Soil Survey)
Central Ground Water Board Google Earth Explorer Census of India

3.2 Field methodology:

After collection of various information regarding the morpho dynamic changes, I have arranged field trip and I have visited many places mainly in the pre-monsoon period, monsoon period and post monsoon period. And have tried to get a relationship of the various aspects which are related to the morpho dynamic changes of Adi Ganga, and tried to understand the Adi Ganga and its connectivity with the Bhagirathi-Hooghly River and Ground water aquifers.

3.3 Post-Field methodology:

After returning back from the field, I have tried to get a co-relationship between various aspects of pre-field information along with the field experience and have generated a hypothesis and tested hypothesis to resolve various plans and development proposals for Kolkata.

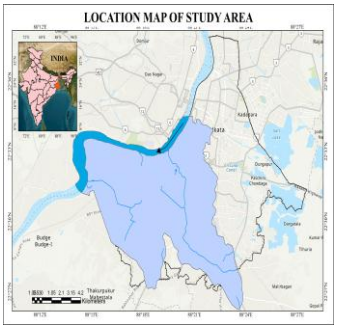
IV. Proposed Research Hypothesis

IV.1. Proposed Primary Hypothesis

Any permanent hydraulic structure that substantially interrupts the natural or managed flow regime of Adi Ganga may disturb the existing hydro-ecological and hydro-geological equilibrium of South Kolkata and may increase environmental risks unless supported by rigorous scientific assessment and adequate environmental safeguards.

IV.2. Proposed Secondary Hypothesis

The restoration of ecological flow, groundwater-surface-water connectivity, wastewater interception and floodplain functionality is likely to provide greater long-term sustainability benefits than converting Adi Ganga into an increasingly engineered hydraulic channel.



V. Historical and Geographical Significance of Adi Ganga

Adi Ganga represents an ancient component of the riverine geography of Kolkata. During different periods of Bengal's history, channels associated with the Hooghly system shifted, declined or became disconnected.

The historical transformation of Adi Ganga was closely related to navigation, drainage and urban development. Major Tolly's intervention in the eighteenth century converted a largely inactive channel into an important navigation and drainage canal. According to the West Bengal Irrigation and Waterways Department, the channel opened in 1777 and extended approximately 17 miles, or 27.2 km, towards the Bidyadhari system.

The river therefore represents an important example of human modification of a natural river system.

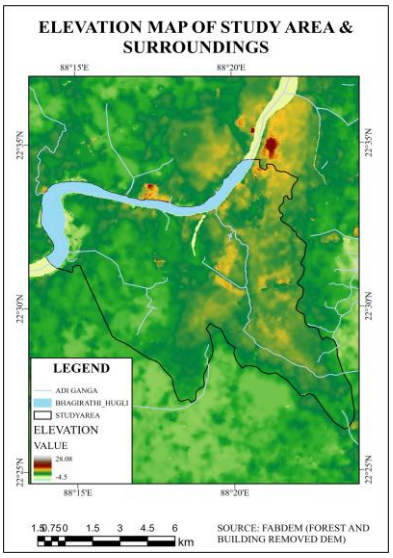
Its present condition illustrates the reverse process: a waterway that once had substantial navigational and hydrological significance has gradually become dominated by wastewater, solid waste, encroachment and engineered structures.

Recent academic research describes the historical degradation of Adi Ganga as a process connected with urbanization, declining river maintenance and the transformation of a functioning riverine corridor into a sewage-bearing urban channel.

VI. Geographical Settings

The geomorphological interpretation of the Adi Ganga study area has been undertaken using four DEM-derived terrain parameters, namely elevation, slope, relative relief and ruggedness index. These parameters represent different aspects of the topographic expression of the inherited fluvial–deltaic surface and are therefore interpreted collectively rather than as independent indicators of groundwater potential. The Adi Ganga represents a paleo channel distributary of the Bhagirathi–Hugli system, and its former course is geomorphologically associated with paleochannel and levee features. The Kolkata sector forms part of the lower deltaic plain, where the terrain is characteristically flat and contains paleochannels, interdistributary depressions and older levees associated with the former Adi Ganga course

6.1 Physiography: The DEM-based elevation map represents the absolute topographic position of the study area. From the map legend, the elevation surface extends approximately from about −0.1 m to about 5 m above the reference level, with the majority of the study area represented by the green portion of the elevation ramp and relatively higher surfaces expressed by yellow to brown tones.



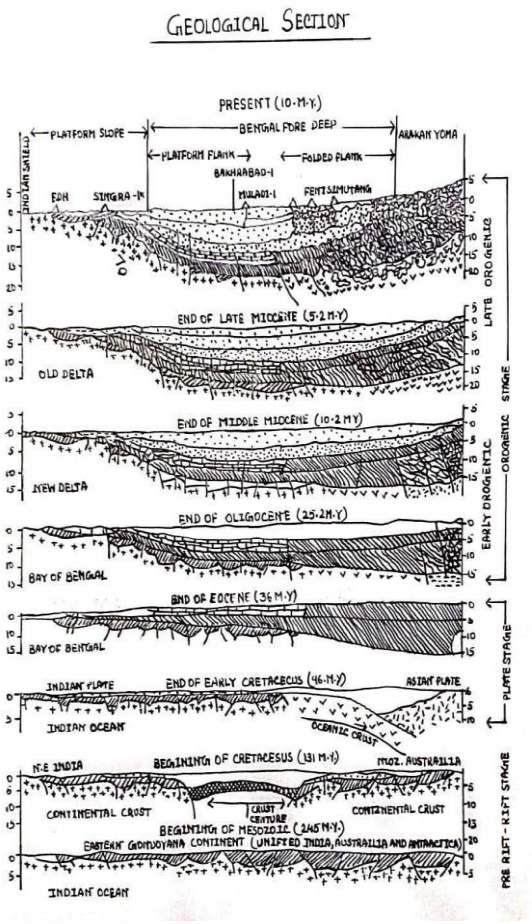
The most important geomorphological observation is that the elevation variation is subdued rather than strongly dissected. The study area therefore does not represent a deeply incised fluvial valley. Instead, it represents a low-gradient depositional surface in which relatively small elevation differences are associated with different fluvial–deltaic depositional units.

The higher elevation zones occur mainly as discontinuous patches and along parts of the surrounding terrain, whereas the Adi Ganga corridor occupies a relatively low topographic position.

In a deltaic environment, a small difference in elevation can be significant. The slightly elevated surfaces adjacent to a former channel may represent natural levee/channel-margin deposits, while relatively lower surfaces can correspond to paleochannel, interdistributary or marsh/backswamp environments. This interpretation is consistent with the documented geomorphology of Kolkata, where older levees on both sides of

the old Adi Ganga, paleochannels and interdistributary marshes occur within the lower deltaic plain.
The elevation pattern can influence local surface-water accumulation, direction of shallow surface drainage, hydraulic gradients and the relative position of recharge and discharge zones. However, elevation itself does not determine groundwater potential. A low-elevation area underlain by clay may have poor vertical infiltration, whereas a slightly elevated sandy paleochannel or levee may have greater permeability. Therefore, the elevation map should be interpreted as showing the topographic framework within which groundwater processes operate, rather than as a direct groundwater-potential map.

6.2 Geological Settings: Ganges Delta basically emerged its shape and configuration on Bengal Fan. The Bengal Fan geo-tectonically is changing its nature and characteristics since Eocene period at phase of geological era a typical hinge has evolved through the East coast of India starting from South-West India ridge and has extended up-to the Dauki fault at the NE India prior to the development of such typical fault line at the end of Dharwar basin margin fault and Dauki fault has developed.



Dauki fault was basically tectonically active shear at the north east India which has gave birth to the dissected flow of Indo-Bram or Shiwalik river system. Simultaneously another drainage divide has occured which is known as Potwar plateau prior to the origin of Himalayas. After the origin of the newly originated streams named as Alaknanda, Mandakini, Bhagirathi etc. had joined with the dissected middle part of the ancient stream and has diverted the streams towards Bengal Fan. The river has met its debouching point just after Rajmahal Hills. At the period of Miocene and Cuddappa the surface of Bengal Fan has repeatedly captured and has developed various other fault like Padma, Pabna, Ghantal fault and various other faulted surface. The phase of Pliocene has just modified the bottom relief of Bengal Fan and has created a surface with low bathymetry which indicate the faster rate of sedimentation over this arcuate fan. Depending on this synaptic structure as parent rock successive textural groups of formation has occured over Bengal Fanas the lithified layers due to the continuous processes of propagating deltaic environment.

If we considered the geological cross section of the area then the sequence will be as follows:

(i) The upper most layer much more soft with fine grained sediments and a balanced textural composition with more or less granular round shape particles. Its water bearing capacity is maximum because of its textural uniqueness and various fine stratified layers arranged successively in this area. The depth of the strata is near about 40-50 mts, with extreme porosity and permeability. That's why these layers normally indicate aquifers of various depth with respect to the topographic variation in this area.

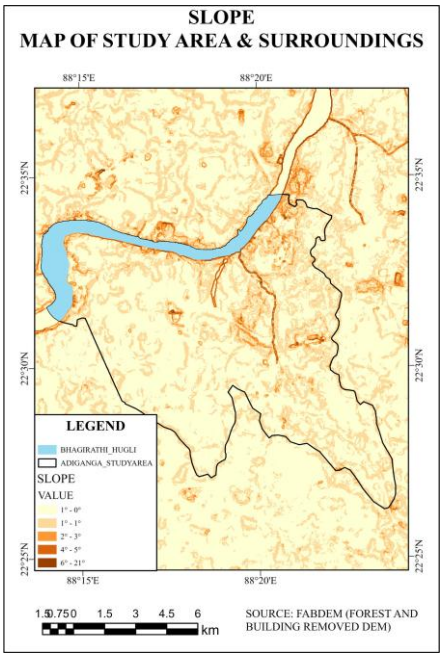
(ii) A typical layer of extremely frazil grains, boulders, pebbles, cobbles and pottery materials which has deposited prior to the formation of Kalighat formation. The extension of the bed is near about 1600 mts. This layer has no aquifers because the variegated nature of composition doesn't permit the water to hold in this layer. In this layer not various activities performed over the surface. Not only that this layer creates passages for the biotic elements to penetrate towards the subsurface condition.

(iii) After these frazil layer to separate beds observed in the sub surface condition. The extension of that two layers are 150-200 mts. These layers normally indicate the occurrence of biotic elements which has passed through the porosity and permeability of the upper rock strata. These two layers are much more stable and are able to carry huge amount of ground water. But at these layers are present at a depth of more than 1800 mts. That's why this water is not easy to pump out for the uses of common people.

(iv) After these typical layers of the Calcium Carbonate prevailed in this area. Through this layer extends up to 4 km. That's why it indicates the depth is near about 2 km. This layer is very much sensitive layer and below this karst layer some fossils are present. This layer is extremely hard but chemically sensitive and below this layer the vast simatic platform of Bengal Fan extents.

VII. Changes of Geographical Condition

7.1 Slope: The slope map is classified into five visible classes, approximately 0–1°, 1–2°, 2–3°, 3–4° and 4–5°. The overwhelming visual dominance of the 0–1° class is one of the most important quantitative observations from the map. The higher slope classes occur only as relatively small and discontinuous patches. This indicates that the Adi Ganga study area is overwhelmingly characterized by a very gentle surface gradient. This result agrees with the regional geomorphological setting of Kolkata, where the lower deltaic plain has a very weak regional gradient towards the south. A terrain dominated by slopes of 0–1° indicates weak gravitational relief, low topographic energy, limited vertical incision, predominantly depositional conditions, low surface-water velocity, and a mature, subdued deltaic surface.

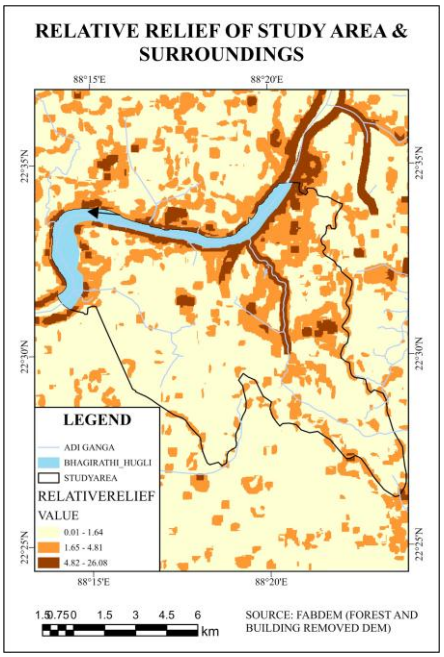


The localized 1–5° slope classes should be interpreted cautiously. They may represent geomorphic breaks around channel/levee margins, but because the Adi Ganga lies within a highly urbanized environment,

some higher-slope pixels may also reflect embankments, roads, built surfaces and other anthropogenic microrelief.

The dominance of 0–1° slope implies that gravitational runoff is relatively weak and that rainfall/surface water can remain on the landscape for longer periods than in steeper terrain. However, low slope does not automatically mean high groundwater recharge. Recharge will depend upon the permeability of the underlying alluvial material. Thus, a 0–1° surface underlain by permeable sandy paleochannel deposits can behave very differently from a 0–1° surface underlain by compact clay and silt.

7.2 Relative Relief: The relative-relief map provides information about local elevation contrast rather than absolute elevation. The map shows a predominantly low-relief background with localized patches of higher relative relief. The lower
visible class is approximately 0.25–0.61, while the upper values extend to approximately 9 units. Because the middle legend boundary is not sufficiently clear in the supplied image, it is not assigned an exact numerical value here.



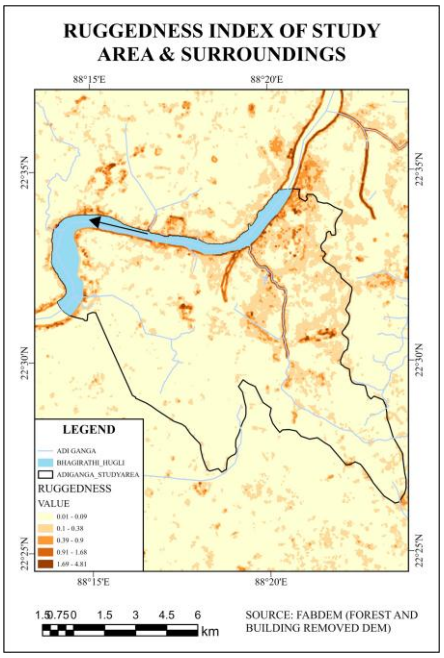
The important geomorphological result is therefore the strong dominance of low relative relief. Low relative relief indicates that the Adi Ganga area has undergone considerable surface smoothing and depositional aggradation, characteristic of a deltaic plain.

The localized higher-relief patches are important
because they may mark transitions between genetically different depositional surfaces. For example, a slightly elevated levee or channel-margin surface may occur adjacent to a lower paleochannel or interdistributary depression. Such subtle relief differentiation is characteristic of a deltaic distributary system.

In a very flat deltaic environment, even a small vertical difference can represent a significant geomorphic boundary. Therefore, low absolute relief does not mean absence of geomorphic differentiation. Instead, the subtle relief differences may
represent the topographic signatures of levee–channel–interdistributary relationships

7.3 Ruggedness Index: The ruggedness map shows five visible classes, approximately 0.1–0.2, 0.2–0.3, 0.3–0.4, 0.4–0.5 and 0.5–0.6, with the lowest ruggedness classes occupying most of the mapped area and higher values occurring in relatively localized patches.

The predominance of low ruggedness indicates a smooth and weakly dissected terrain surface. When considered together with the elevation range of approximately −0.1 to 5 m, the dominance of 0–1° slope, and the predominantly low relative relief, the ruggedness pattern confirms the smooth, low-gradient nature of the deltaic surface.



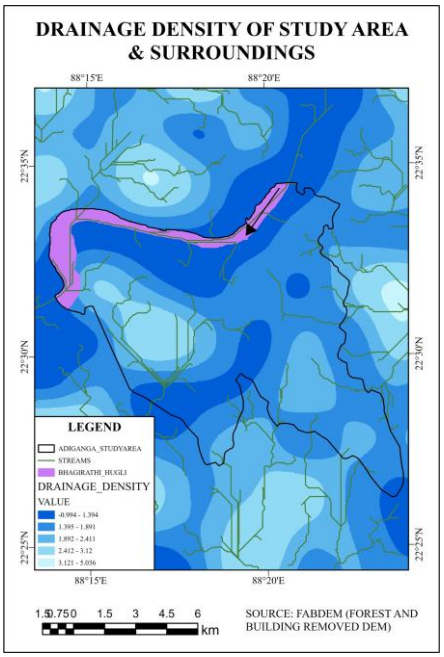
The higher ruggedness values should not automatically be interpreted as natural erosional features. In the present urban landscape, surface roughness can also be generated by roads, buildings, bridges, embankments, artificial fills and channel banks. Therefore, localized high-ruggedness zones may represent a combination of inherited geomorphic microrelief and anthropogenic modification.

VIII. Groundwater Study

8.1 Spatial Distribution of Drainage Density in the Adi Ganga Study Area and Surroundings

The drainage density map illustrates the **spatial variation in drainage concentration** across the Adi Ganga study area and its surrounding region.

The drainage density values range from approximately **–0.994 to 5.036**, indicating considerable spatial heterogeneity in the drainage network.



Higher drainage-density zones, represented by the **lighter blue shades**, are mainly distributed across parts of the **southern, south-western and peripheral areas** of the study region. These areas indicate a relatively greater

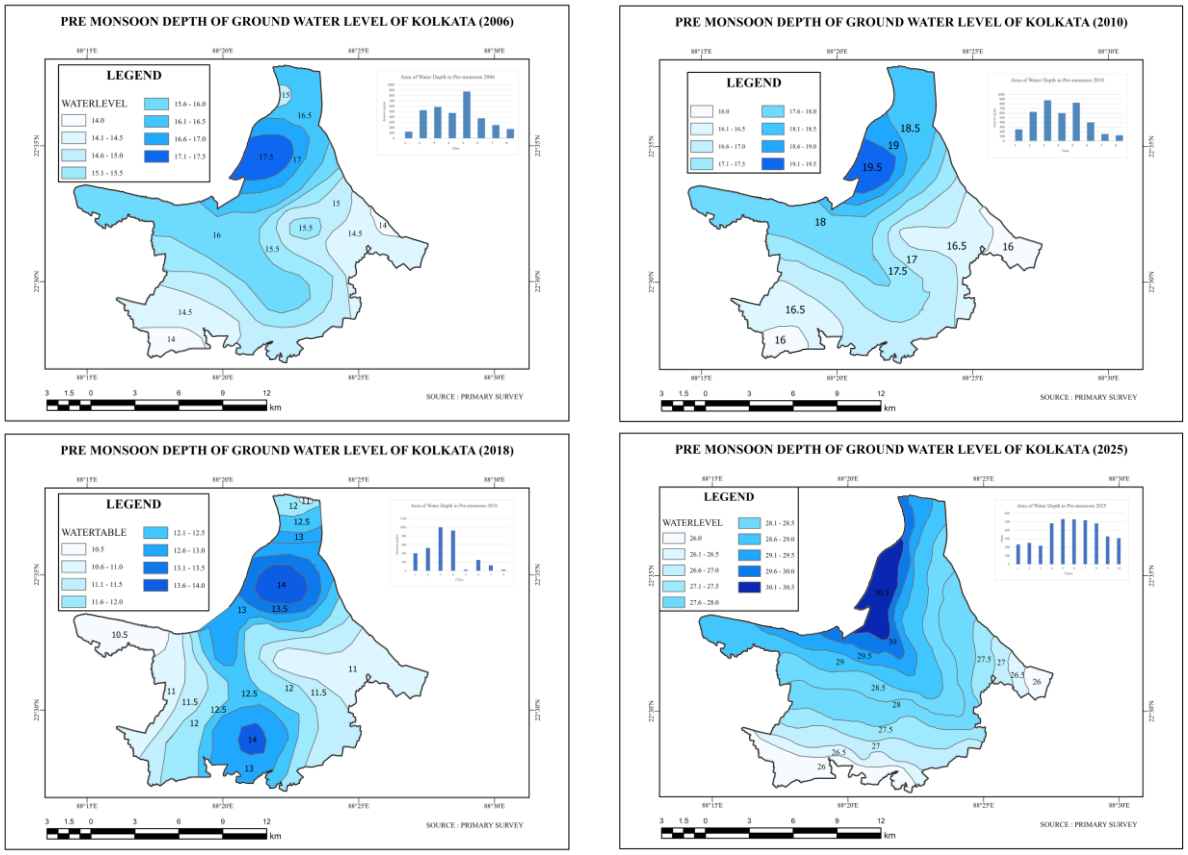
concentration of stream channels and potentially enhanced surface-water connectivity. In contrast, **lower drainage-density values**, shown by darker blue shades, occur in several parts of the **central and northern sections**, indicating comparatively sparse drainage development.

The **Adi Ganga channel and its associated drainage network** form an important longitudinal drainage feature within the study area, connecting with the wider **Bhagirathi–Hugli river system**. The spatial variation in drainage density may be influenced by **surface** morphology, elevation, slope, land-use characteristics and the degree of urban modification.

For the Adi Ganga environment, areas with relatively high drainage density may experience greater surface runoff and drainage concentration, whereas low-density zones may indicate **restricted natural drainage connectivity**. Overall, the map highlights the heterogeneous drainage characteristics that are important for understanding **urban drainage behavior, waterlogging potential and environmental degradation** in the study area.

8.2 Pre-Monsoon Groundwater Depth (2006–2025)

The pre-monsoon groundwater-depth maps indicate considerable spatial and temporal variation in groundwater conditions across Kolkata. In 2006, groundwater depth ranged from approximately 14.0 to 17.5 m, with the greatest depths concentrated in the northern part, while relatively shallow levels occurred mainly in the southern and eastern margins.



In 2010, the depth increased to about 16.0–19.5 m, maintaining a similar north–south spatial pattern and indicating greater pre-monsoon groundwater depletion compared with 2006. In

2018, however, groundwater depth decreased markedly to approximately 10.5–14.0 m. The deepest levels were concentrated in the northern and southern-central pockets, whereas shallower levels occurred mainly in the western and eastern parts. This represents a substantial spatial and temporal shift from the preceding years.

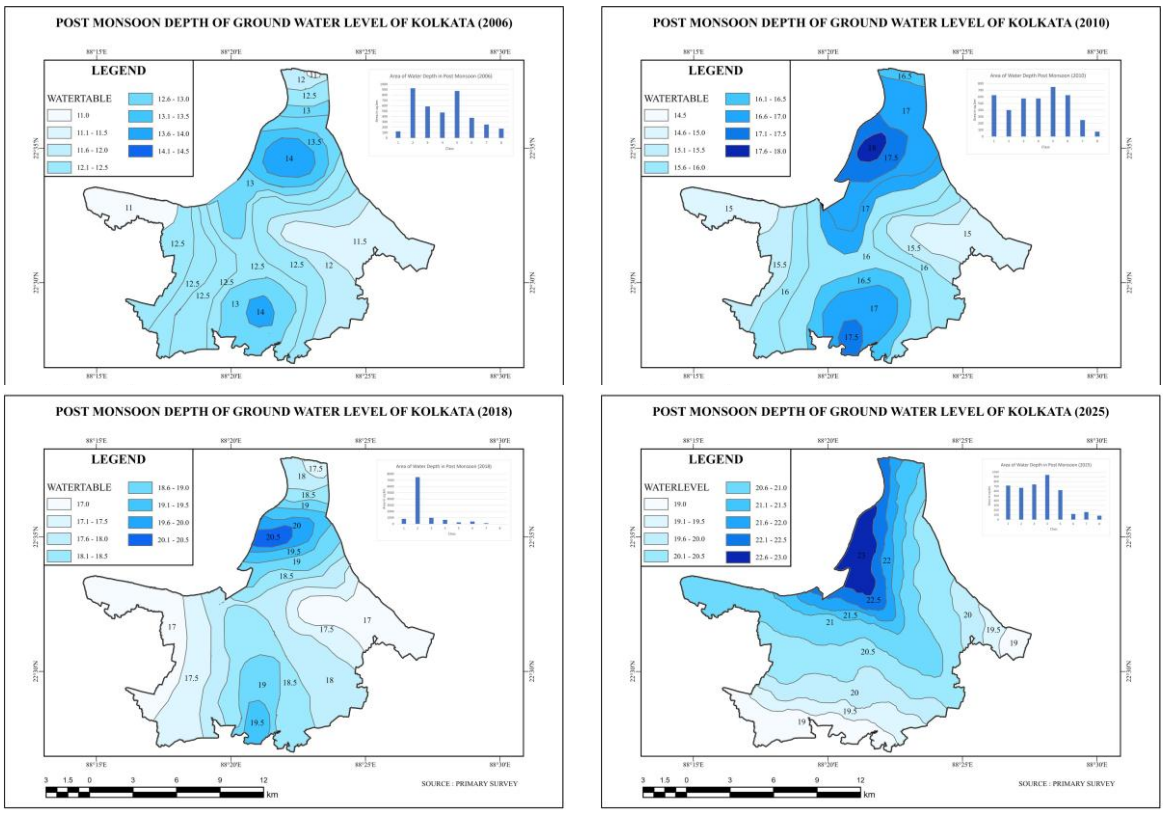
By 2025, groundwater depth increased sharply to approximately 26.0–30.5 m. The maximum depth occurred in the northern sector, while progressively shallower groundwater levels extended toward the southern and

southeastern margins.

Overall, the maps show a strong long-term increase in pre-monsoon groundwater depth, particularly between 2018 and 2025. The pattern indicates substantial temporal fluctuation and increasing groundwater-level stress by 2025, although the causes require supporting hydrogeological and groundwater-extraction data.

8.3 Post-Monsoon Groundwater Depth (2006–2025)

The post-monsoon groundwater-depth maps of Kolkata indicate a progressive deepening of the groundwater table between 2006 and 2025.



In 2006, groundwater depth varied approximately from 11.0 to 14.5 m, with the deepest groundwater levels concentrated in the northern and central parts, while comparatively shallow levels occurred toward the western and eastern margins. In 2010, the depth increased to about 14.5–18.0 m, showing a substantial decline in groundwater levels.

By 2018, groundwater depth further increased to approximately 17.0–20.5 m. The northern sector recorded the greatest depths, while relatively shallow groundwater persisted in the peripheral and southern areas. In 2025, the range increased further to about 19.0–23.0 m, with maximum depths concentrated in the northern part and progressively shallower conditions toward the southern and southeastern margins.

Overall, the maps demonstrate a consistent temporal deepening of the post-monsoon groundwater table, with the maximum recorded depth increasing from about 14.0 m in 2006 to 23.0 m in 2025. This spatial and temporal pattern indicates increasing groundwater-level decline, potentially reflecting groundwater abstraction, urbanization, reduced infiltration and modification of natural drainage. However, attribution to individual factors requires supporting groundwater-use and hydrogeological data.

8.5 Post-Monsoon Groundwater Level Variation in Kolkata (2006–2025)

The post-monsoon groundwater-level maps show a clear temporal increase in groundwater depth across Kolkata between 2006 and 2025. In 2006, groundwater depth ranged approximately from 11.0 to 14.5 m, with relatively deeper levels concentrated in the northern and central parts, while shallower levels occurred mainly toward the western and eastern margins. By 2010, the range increased to about 14.5–18.0 m, indicating a general

deepening of the groundwater table.

In 2018, groundwater depth further increased to approximately 17.0–20.5 m, with the deepest levels concentrated in the northern sector and relatively shallower conditions in the southern and eastern portions. By 2025, the depth reached about 19.0–23.0 m, with the maximum depth concentrated in the northern part and progressively shallower levels toward the southern and southeastern margins.

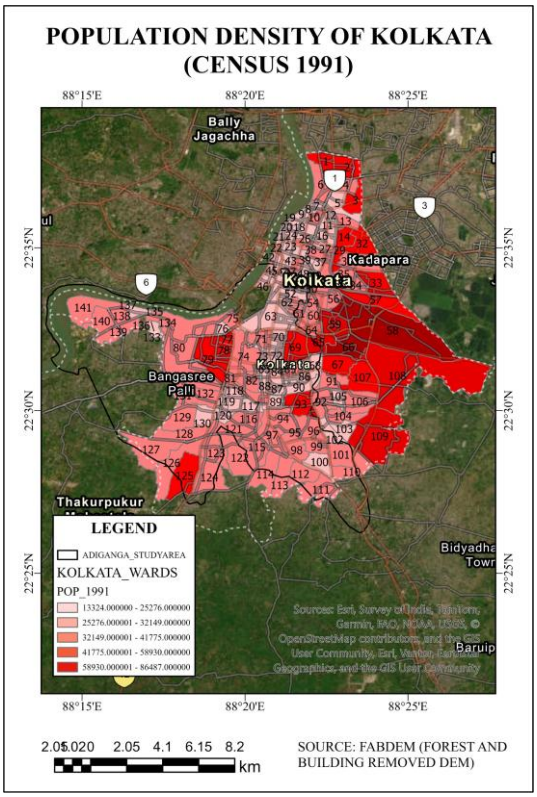
Overall, the maps indicate a progressive deepening of the post-monsoon groundwater table, with the approximate maximum depth increasing from 14 m in 2006 to 23 m in 2025. This

pattern suggests increasing groundwater-level decline over time and indicates spatially uneven groundwater stress across Kolkata. The pronounced deepening may be associated with increasing groundwater abstraction, urbanisation, reduced infiltration and changes in surface-water drainage, although these factors require supporting hydrogeological data for confirmation.

IX. Changes in Various Sphere

9.1 Spatial and Temporal Variation in Population Density of Kolkata (1991–2011)

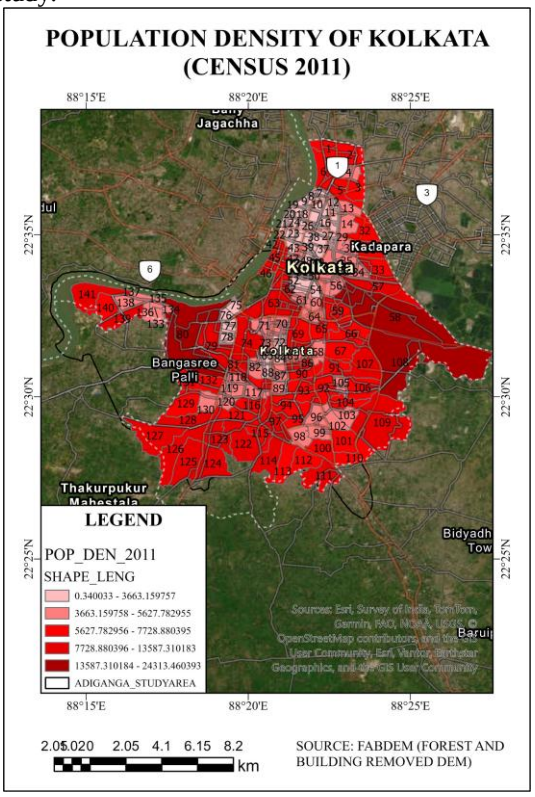
The maps illustrate the **spatial distribution and temporal change in population density across Kolkata's wards between the 1991 and 2011 Census periods** within the Adi Ganga study area.



In **1991**, population density shows considerable spatial variation. The relatively lower-density wards are concentrated mainly toward the **southern and south-western margins**, while higher population concentrations occur predominantly in the **central and eastern parts of Kolkata**. This indicates an established urban core with comparatively less densely populated peripheral areas.

By **2011**, the spatial pattern had changed substantially. A marked **increase in population density is evident across a large number of wards**, particularly in the central, southern and south-eastern portions of the study area. Several peripheral wards that displayed relatively lower population density in 1991 also show considerably higher values by 2011. This suggests **continued urbanization, residential expansion and increasing population concentration** over the two-decade period.

The intensification of population density around the **Adi Ganga corridor and adjoining urban wards** is particularly significant for the study.



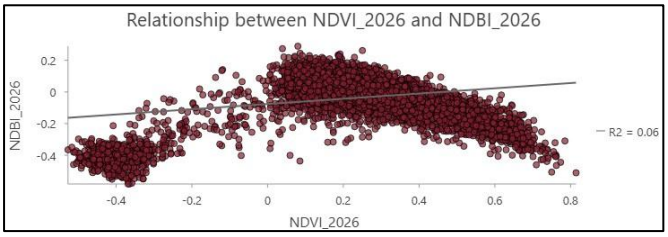
Increasing population pressure can contribute to greater **land-use transformation, wastewater generation, solid-waste accumulation, encroachment and pressure on the drainage system**. Therefore, the observed demographic intensification provides an important spatial context for assessing the **environmental degradation and urban encroachment of the Adi Ganga channel**.

9.2 Co-relation Between Urbanization and Climate Change of Kolkata

Climate change and urbanisation are closely interconnected in the Adi Ganga basin of South Kolkata. Rapid urbanisation has transformed the natural landscape of the basin through construction of buildings, roads, drainage infrastructure and other impervious surfaces. At the same time, the loss of wetlands, ponds, vegetation and open spaces has reduced the natural capacity of the basin to store and infiltrate rainwater.

Climate change is increasing the importance of these changes. Rising temperatures and changes in monsoon behaviour can increase the occurrence of short-duration, high-intensity rainfall events. In a densely urbanised basin, much of this rainfall rapidly becomes surface runoff because concrete and asphalt prevent infiltration. Consequently, the drainage system and the Adi Ganga channel may
experience excessive hydraulic pressure, increasing the possibility of urban waterlogging and flooding.

Urbanisation also contributes to the urban heat-island effect, in which built-up areas become warmer than surrounding less-developed areas. Higher temperatures can worsen water-quality problems, particularly where the river has low flow and receives untreated sewage



and other pollutants. Reduced groundwater recharge caused by impervious surfaces may further disturb the local hydrological balance.

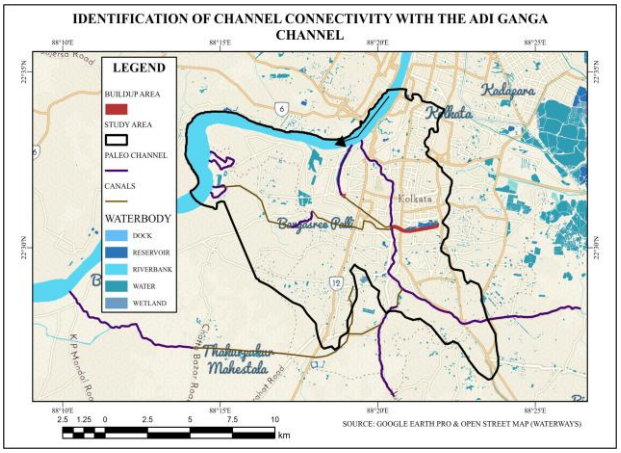
The relationship is therefore bidirectional. Climate change intensifies rainfall, heat and hydrological stresses, while unplanned urbanisation reduces the basin's natural ability to absorb these stresses.

Thus, protecting the Adi Ganga requires an integrated approach involving wetland conservation, restoration of natural drainage, improvement of sewage management, increased green spaces, rainwater harvesting, groundwater recharge and climate-resilient urban planning. The long-term environmental sustainability of South Kolkata depends partly on maintaining the ecological and hydrological functions of the Adi Ganga basin.

X. Scenario Modelling

10.1 Spatial Analysis of Hydrological Connectivity in the Adi Ganga System

The map illustrates the spatial connectivity of the Adi Ganga channel with surrounding palaeochannels, canals and surface-water bodies within the study area. The Adi Ganga corridor forms a major drainage pathway through the urban landscape, while several secondary canals and palaeochannels intersect or approach it, indicating a historically interconnected fluvial network.

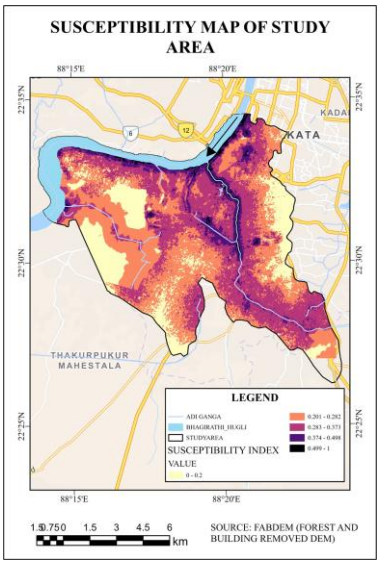


The palaeochannels, represented in purple, suggest remnants of former drainage pathways that may reflect past channel course shifting and changes in river morphology. The canals, shown in brown, provide additional artificial or modified drainage connections between water bodies and the Adi Ganga system.
The map also shows extensive water bodies, wetlands, reservoirs and riverbank areas, particularly toward the western and eastern margins, indicating the persistence of hydrological features within the urban environment. However, the highly built-up surroundings demonstrate substantial urban encroachment around these drainage corridors. Such land-use transformation can reduce natural drainage connectivity, restrict water movement and increase the risk of waterlogging and flooding.
Overall, the spatial pattern indicates that the Adi Ganga is part of a historically connected but increasingly fragmented urban drainage network, influenced by both natural fluvial processes and anthropogenic modifications.

10.1 Susceptibility Map of the Study Area

The susceptibility map shows considerable spatial variation in susceptibility across the study area, with index values ranging from 0 to 1. The lowest susceptibility class (0–0.20) is mainly distributed in the western, southwestern and some peripheral portions of the study area. Moderate susceptibility (0.201–0.373) occurs extensively across the central, southern and eastern sectors.

Higher susceptibility values (0.374–0.498) are concentrated mainly in the central and northern parts of the study area, with several continuous zones extending along the major
drainage corridors. The highest susceptibility class (0.499–1.00) occurs as relatively localized patches, particularly in the central and northern sectors and in parts of the southern drainage corridor.

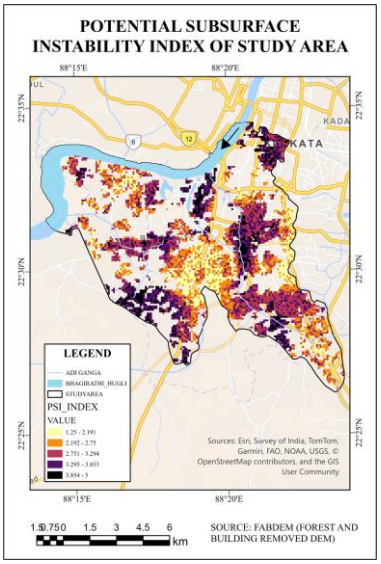


The spatial pattern indicates that susceptibility is not uniform and that areas surrounding major drainage features show comparatively higher index values in several locations. The concentration of higher susceptibility within the urbanized study area suggests that these zones may require greater consideration in environmental and land-management planning.

Overall, the map identifies distinct low-, moderate- and high-susceptibility zones, providing a spatial basis for prioritizing areas for further field investigation and management. As this is an index-based assessment, the susceptibility classes should be validated with relevant field and environmental data.

10.2 Potential Subsurface Instability Index

The Potential Subsurface Instability Index (PSI) map shows considerable spatial variation in subsurface instability across the study area, with index values ranging from 1.25 to 5.00. The lowest PSI class (1.25–2.191) is widely distributed, particularly in scattered peripheral and relatively less concentrated areas. Moderate instability (2.192–3.294) occurs extensively across the central and southern portions of the study area.



Higher PSI values (3.295–3.853) are concentrated in several distinct clusters, particularly along the central urban corridor and parts of the eastern and southern sectors. The highest PSI class (3.854–5.00) forms prominent clusters around the central portion, northern–central urban areas, and parts of the southern corridor. These zones represent areas of comparatively greater potential subsurface instability according to the mapped index.

The spatial concentration of higher PSI values near developed areas and drainage corridors suggests that these locations warrant greater attention in environmental and urban planning assessments. However, the PSI map represents an index-based assessment; therefore, the identified zones should be validated using field observations and geotechnical or subsurface data before engineering decisions are made.

A healthy river continuously transports sediment.
If a barrier interrupts this process, sediment may accumulate upstream while sediment-starved water may occur downstream.
Over time this can change - channel geometry, bed elevation, bank stability, flood-carrying capacity.

Recent research on Adi Ganga has reported shallow water, sediment deposition, poor discharge and structural barriers affecting water movement along parts of the channel.

A further hydraulic barrier could therefore intensify an already existing problem if not scientifically designed and managed.

10. Possible Consequences for Groundwater

A barrage can change groundwater conditions in two opposing ways.

Positive possibility
In some circumstances, increased upstream water levels can enhance local infiltration.

Negative possibility
However, if the water is polluted, enhanced infiltration may facilitate the movement of contaminants into shallow groundwater.

Furthermore, if downstream river levels fall because of altered flow, the hydraulic gradient between groundwater and the river could change.

The net result cannot be predicted merely from the existence of a barrage.
It requires a site-specific groundwater model. Therefore, the argument should not be:
"A barrage will definitely destroy Kolkata's groundwater." The scientifically defensible argument is:
"A barrage could alter the hydraulic relationship between Adi Ganga and adjoining aquifers; therefore, its groundwater consequences must be assessed before construction."

11. Isostasy versus Local Geo-Hydrological Equilibrium
The term isostatic balance requires special scientific clarification.
Classical isostasy refers to the gravitational equilibrium between the Earth's lithosphere and underlying mantle.
It operates over geological spatial and temporal scales.

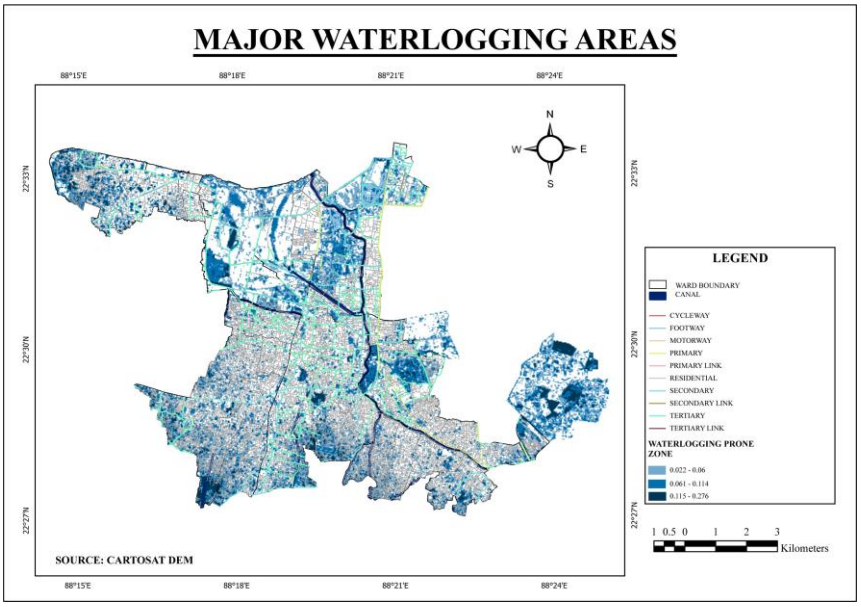
The water stored in an urban river is not sufficiently large to control the regional isostatic equilibrium of Kolkata. However, this does not mean that water-level and groundwater changes are geographically insignificant.

Urban areas can experience local ground deformation and subsidence due to- groundwater withdrawal, consolidation of compressible sediments, loading by buildings and infrastructure, drainage of organic-rich soils, changes in pore-water pressure, sediment compaction.

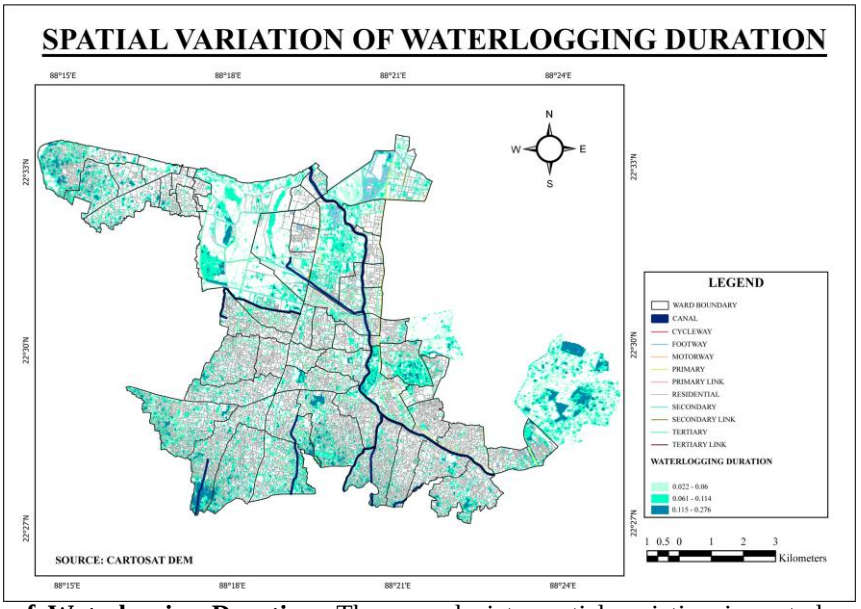
Therefore, the appropriate concept for Adi Ganga is: Hydro-geotechnical equilibrium rather than classical isostasy.
Maintaining groundwater levels and natural drainage is consequently important for maintaining the physical stability of a low-lying urban environment.

12. Adi Ganga and Urban Flood Management
South Kolkata receives intense monsoonal rainfall. Large areas are increasingly covered by roads, buildings, concrete surfaces and other impervious materials. This reduces natural infiltration and increases rapid surface runoff. The urban drainage system therefore depends heavily on the capacity of canals and outfalls.
Historically, Adi Ganga and the connected canal system formed part of Kolkata's drainage and navigation network. The development of the city's drainage infrastructure subsequently

included other canals and outfall systems.
A barrage that restricts flow could therefore become a potential hydraulic bottleneck if its operation is not coordinated with-rainfall, tide, upstream drainage,
downstream water level, pump operation, canal discharge & stormwater inflow.



During extreme rainfall, even a relatively small reduction in effective drainage capacity may increase waterlogging.
Major Waterlogging Areas: The map illustrates the spatial distribution of waterlogging-prone areas, classified into three categories according to mapped values. Higher values (0.115–0.276) occur in several concentrated patches, particularly in the southern, central, and northern sectors. Their distribution is spatially heterogeneous, with lower values interspersed across the study area.



Spatial Variation of Waterlogging Duration: The map depicts spatial variation in waterlogging duration, represented by three classes ranging from 0.022–
0.276. Higher values
(0.115–0.276) are
concentrated in scattered patches, including parts of the northern, central, and southern sectors. Lower-duration classes are more widely distributed. This spatial heterogeneity indicates variation in mapped waterlogging persistence.

13. Ecological Consequences

A river is an ecological corridor even when it is heavily degraded.

Its water, sediments, banks and vegetation provide habitats for microorganisms, insects, fish, birds and other organisms.

A permanent hydraulic barrier may- divide aquatic habitats, alter water temperature, change dissolved oxygen, increase pollutant residence time, affect aquatic organisms, modify sediment habitats & alter vegetation patterns.
The National Green Tribunal has repeatedly treated Adi Ganga as a river requiring restoration and rejuvenation. In its 2020 directions, the Tribunal called for restoration, prevention of untreated wastewater and solid-waste discharge, removal of encroachments and preparation of a river-restoration scheme.
This regulatory approach is important because it recognises that the solution to river degradation is rejuvenation, not simply further transformation of the river into a closed engineered drain.

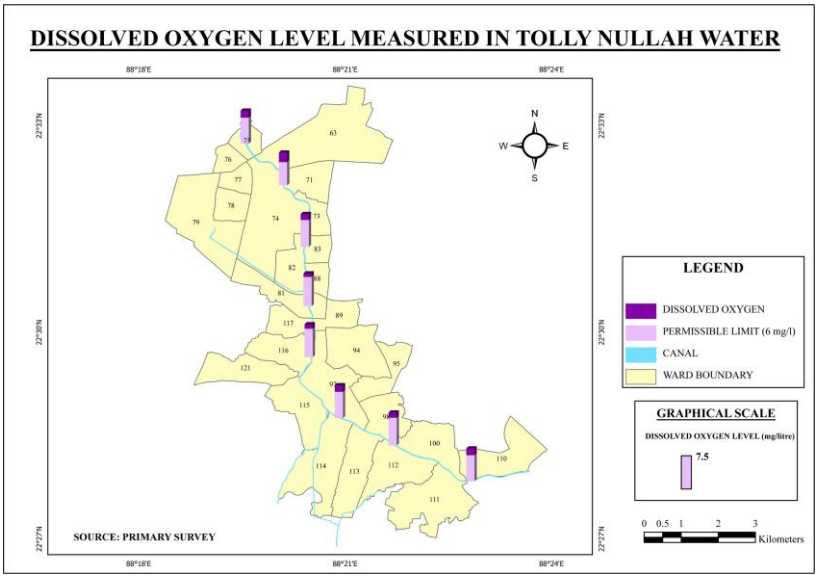
14. Pollution and the Barrage Question

The existing pollution problem makes the barrage question particularly sensitive.
If polluted water enters a slowly moving impounded section, the residence time of contaminants can increase.

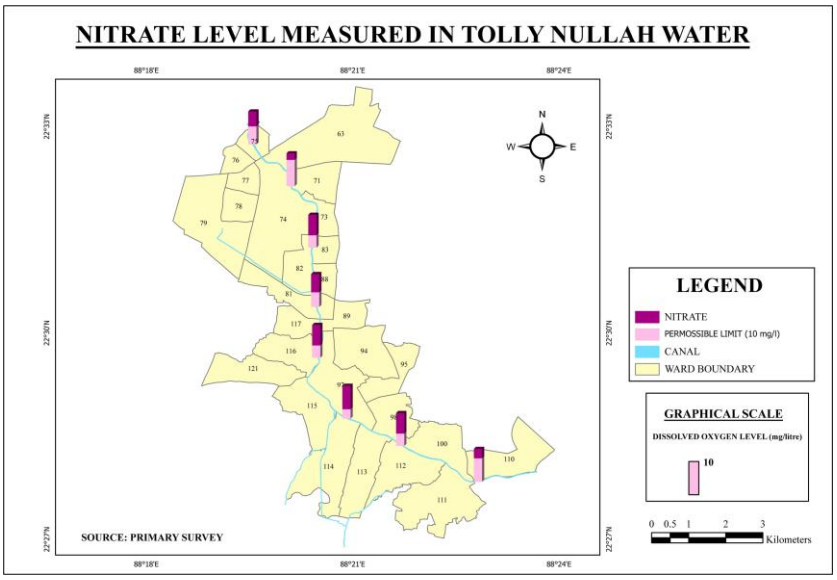
The result may be:
Wastewater input → reduced velocity → longer residence time → oxygen depletion → organic decomposition → odour → ecological degradation

1. Dissolved Oxygen (DO) Level

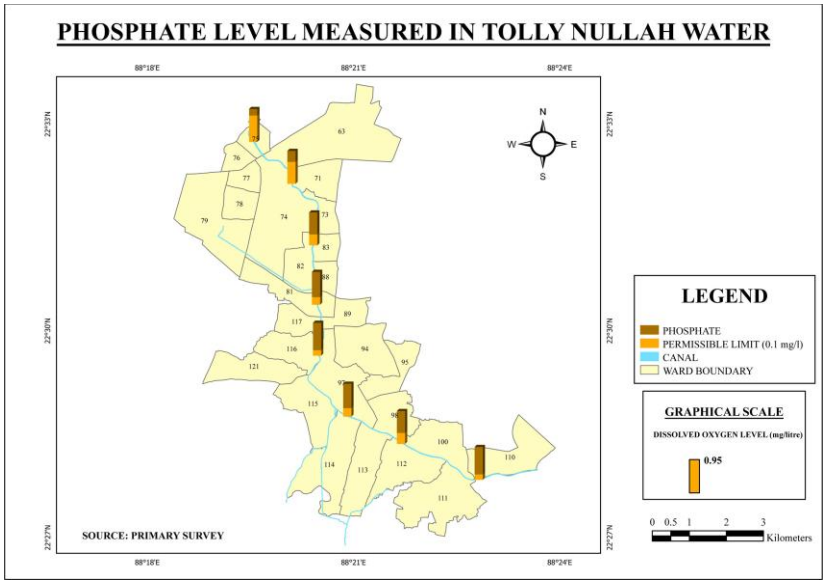
The dissolved oxygen map illustrates the variation in DO levels at different sampling locations along the Tolly Nullah. The measured values are compared with the permissible limit of 6 mg/L. The spatial variation in oxygen concentration indicates differences in water quality along the canal. Lower DO levels may reflect increased organic pollution and oxygen consumption, potentially affecting aquatic life.



2. Nitrate Level The nitrate map presents the concentration of nitrate at selected sampling locations along the Tolly Nullah in comparison with the permissible limit of 10 mg/L. The observed spatial variation suggests differences in nutrient loading along the canal. Elevated nitrate concentrations may indicate inputs from domestic wastewater and other urban sources, highlighting the need to monitor nutrient pollution.



3. Phosphate Level



The phosphate map shows the phosphate concentrations recorded at sampling locations along the Tolly Nullah against the permissible limit of 0.1 mg/L. The variation in phosphate levels indicates differences in nutrient enrichment along the canal. Increased phosphate concentrations may be associated with wastewater discharge and urban runoff, potentially promoting excessive algal growth and eutrophication.

This creates a fundamental planning principle: Hydraulic intervention should never substitute for pollution control. The first priority should be to intercept untreated sewage and industrial wastewater.
The National Green Tribunal has previously directed authorities to prevent untreated wastewater and solid waste from entering Adi Ganga and to undertake restoration measures.

15. Cultural and Social Importance

Adi Ganga also possesses extraordinary cultural significance. The river corridor contains historic ghats, temples, settlements and cultural landscapes. Academic research has described Adi Ganga as a river whose ecological degradation has occurred alongside urban development and social displacement.
Consequently, river restoration should not be restricted to engineering.
It should integrate- cultural heritage, local communities, religious institutions, traditional riverfront spaces, ecological restoration, public health & urban landscape design.

16. The "Dam versus River Restoration" Question

The central policy question should not be whether a dam is technically possible. It should be:
What is the least destructive intervention capable of achieving the required drainage, flood-control or water-management objective?

If the objective is flood control, alternatives may include- de-siltation at scientifically identified locations, removal of hydraulic obstructions, sewage interception, increased pumping capacity where appropriate, restoration of connected canals, floodplain protection, rainwater harvesting, permeable urban surfaces, detention ponds, wetland conservation & real-time drainage management.
A permanent barrage should be considered only after demonstrating that these less intrusive alternatives are inadequate.

17. Recommended Environmental Impact Assessment

Before any dam, barrage, sluice or permanent hydraulic barrier is constructed, the following studies should be mandatory:

A. Hydrological Assessment

- rainfall-runoff modelling;
- peak discharge;
- flood-frequency analysis;
- tidal interaction;
- upstream and downstream flow conditions.

B. Groundwater Assessment

- seasonal groundwater monitoring;
- aquifer mapping;
- groundwater-flow modelling;
- groundwater-quality assessment;
- subsidence monitoring.

C. Sediment Assessment

- sediment load;
- deposition rate;
- channel morphology;
- erosion potential;
- downstream sediment deficit.

D. Ecological Assessment

- fish;
- plankton;
- aquatic vegetation;

- birds;
- benthic organisms;
- riparian vegetation.

E. Pollution Assessment

- BOD;
- COD;
- DO;
- pH;
- TDS;
- heavy metals;
- nutrients;
- microbial contamination.

F. Social Impact Assessment

- affected settlements;
- livelihoods;
- religious/cultural sites;
- public access;
- rehabilitation requirements.

18. Proposed Sustainable Management Model

The future of Adi Ganga should be based on a River–Aquifer–Wetland–City Integrated Management Model.

Pillar 1: Restore Flow
Maintain an appropriate ecological and hydraulic flow regime.

Pillar 2: Stop Pollution
No untreated sewage or industrial wastewater should enter the river.

Pillar 3: Protect Groundwater
Establish a network of groundwater observation wells along the river.

Pillar 4: Protect the River Corridor
Prevent further encroachment on the channel and its functional floodplain.

Pillar 5: Scientific Desiltation
Desiltation should be based on sediment studies rather than indiscriminate excavation.

Pillar 6: Nature-Based Solutions
Introduce wetlands, riparian vegetation, bioengineering and permeable surfaces wherever possible.

Pillar 7: Continuous Monitoring
A real-time monitoring system should measure- rainfall, river stage, discharge, groundwater level, water quality, sediment & dissolved oxygen.

19. A Proposed "Adi Ganga Environmental Observatory"

A particularly useful long-term research initiative would be the establishment of an Adi Ganga Environmental Observatory.

It could integrate:
Rainfall + River Flow + Groundwater + Sediment + Water Quality + Biodiversity + Land Subsidence +

Urban Drainage into one GIS-based platform.
Satellite remote sensing and field observations could be combined to monitor changes in- river width, water spread, encroachment, vegetation, sedimentation, land-use change, flood inundation.
Such an observatory would transform Adi Ganga management from a reactive engineering exercise into a science-based adaptive management system.

20. Context
Adi Ganga, originally a distributary of the Bhagirathi-Hooghly system, is now Tolly's Nullah (excavated in 1777 by Major Tolly). It extends 27.2 km to the Bidyadhari system at Samukpota. Though severely degraded, polluted and silted, it remains a functional hydro-ecological corridor of South Kolkata. The contemporary policy debate is whether to construct a permanent dam/barrage across it for drainage/flood control.

Primary Hypothesis:
Any permanent hydraulic structure that substantially interrupts the natural or managed flow regime of Adi Ganga may disturb the existing hydro-ecological and hydro-geological equilibrium of South Kolkata and may increase environmental risks unless supported by rigorous scientific assessment and adequate environmental safeguards.

This hypothesis proposes that Adi Ganga is not a dead drain but a living system whose channel, sediments, banks, groundwater interactions, tidal exchange, drainage functions and ecological processes are interconnected. A barrage will alter critical parameters:

1. **Hydraulic:** Water levels, flow velocity, flood conveyance, tidal prism.
2. **Geomorphic:** Sediment transport, siltation pattern, bank stability.
3. **Hydrogeological:** Surface water - groundwater connectivity, groundwater gradient, aquifer recharge, water quality. Research cited in the study (Chemosphere) already shows pollution of Adi Ganga surface water is associated with degradation of adjoining groundwater.
4. **Ecological:** Dissolved Oxygen (DO) depletion, increased pollutant residence time, habitat fragmentation, loss of aquatic organisms. The sequence would be: wastewater input -> reduced velocity -> longer residence time -> oxygen depletion -> organic decomposition -> odour -> ecological degradation.
5. **Urban Risk:** Increased waterlogging on one side, soil moisture imbalance, and potential hydro-geotechnical instability. The study clarifies that the claim of direct geological isostatic control by Adi Ganga is scientifically appropriate and local hydro-geotechnical equilibrium, drainage and land stability may still be affected.

The consequences will depend on design, location, operating regime, tidal condition, pollution load and monsoon intensity, therefore cannot be assumed as risk-free.

Secondary Hypothesis:
The restoration of ecological flow, groundwater-surface-water connectivity, wastewater interception and floodplain functionality is likely to provide greater long-term sustainability benefits than converting Adi Ganga into an increasingly engineered hydraulic channel.

This means the least destructive intervention principle should be adopted. Instead of asking "Can we construct a barrage?", the policy question should be "What is the least destructive intervention capable of achieving drainage/flood control?"

Alternative measures include: scientific de-siltation, removal of hydraulic obstructions, sewage interception before entry, increased pumping capacity, restoration of connected canals, floodplain protection, rainwater harvesting, permeable surfaces, detention ponds, wetland conservation, and real-time drainage management.

A barrage should only be considered after proving these alternatives inadequate.

Testability:
The hypothesis will be tested through threefold methodology: Pre-field (satellite images, DEM from Google Earth Engine, NBSS soil data, CGWB groundwater data, Census, Irrigation Dept records), Field (pre-monsoon, monsoon, post-monsoon observations of morpho-dynamics and connectivity with Bhagirathi-Hooghly and aquifers), and Post-field (correlation, modelling, EIA framework, flood-routing and sediment-budget modelling, continuous groundwater monitoring, land-subsidence monitoring via GNSS/InSAR).

21. Major Findings

The analysis leads to the following principal findings:

1. Adi Ganga is an important historical component of Kolkata's riverine and drainage geography.
2. It remains connected to the broader hydro-ecological system of South Kolkata.
3. Scientific research demonstrates a relationship between pollution of Adi Ganga surface water and degradation of adjoining groundwater.
4. The river's present degradation is already associated with reduced flow, sedimentation, wastewater and structural constraints.
5. A barrage would potentially alter water levels, flow velocity, sediment transport and groundwater-surface-water interaction.
6. The consequences would depend on the exact design, location, operating regime, tidal condition, groundwater gradient and pollution load.
7. The claim that Adi Ganga directly maintains the geological isostatic balance of Kolkata is not scientifically appropriate.
8. Nevertheless, maintaining its hydrological functions may be important for local hydro-geotechnical equilibrium, drainage, groundwater conditions and urban environmental stability.
9. Restoration of Adi Ganga is consistent with directions previously issued by the National Green Tribunal.
10. Any new permanent hydraulic barrier should therefore be preceded by a comprehensive cumulative environmental and hydrogeological assessment.

22. Conclusion

Adi Ganga should not be regarded as a useless or obsolete drainage channel simply because its present condition is degraded.

A degraded river is still a river system.

Its channel, sediments, banks, groundwater interactions, drainage functions, ecological processes, cultural landscape and relationship with surrounding urban settlements constitute a complex environmental system.

The scientific evidence already available indicates that surface-water pollution in Adi Ganga is associated with deterioration of groundwater quality. The National Green Tribunal has also recognised the necessity of restoration and rejuvenation of the river and prevention of untreated wastewater and solid-waste discharge.

Therefore, the future policy of South Kolkata should not be based upon the assumption that the river can be freely converted into an engineered hydraulic channel without consequences.

A barrage may sometimes provide a specific engineering benefit, but its wider consequences must be examined.

The crucial question is not:

"Can we construct a barrage across Adi Ganga?"

The crucial question is:

"Can Kolkata afford to alter one of its remaining hydro-ecological corridors without understanding its consequences for groundwater, drainage, sediment, ecology and urban resilience?"

The answer should be no.

Before any permanent intervention is undertaken, Kolkata needs a comprehensive Adi Ganga River Basin and Urban Hydrogeological Assessment. The river should be restored rather than merely restrained. Its ecological flow should be protected rather than unnecessarily interrupted. Its groundwater relationship should be monitored rather than ignored. Its floodplain should be treated as an environmental asset rather than vacant urban land. And its cultural heritage should be incorporated into restoration planning.

The long-term sustainability of Kolkata depends not on eliminating natural water systems but on learning how to live with them. Adi Ganga should therefore be recognised as a "Living Hydro-Ecological Corridor of South Kolkata."

Its restoration is not merely an environmental beautification programme. It is an investment in groundwater security, flood resilience, ecological health, cultural heritage and the long-term sustainability of Kolkata itself.

23. Policy Recommendations Immediate Recommendations

1. No new permanent dam/barrage should be approved without a comprehensive independent Environmental Impact Assessment.
2. A detailed Surface Water–Groundwater Interaction Study should be undertaken along the entire Adi Ganga corridor.
3. Untreated sewage and industrial wastewater must be intercepted before entering the river.
4. The river's ecological flow and hydraulic connectivity should be maintained.
5. Encroachments and structural obstructions affecting drainage should be scientifically mapped and addressed.
6. Groundwater levels should be monitored continuously along both banks.
7. A land-subsidence monitoring network using precise levelling, GNSS and satellite InSAR should be established in vulnerable areas.
8. Any proposed barrage should undergo flood-routing, sediment-budget and groundwater modelling for multiple monsoon and extreme-rainfall scenarios.
9. Nature-based drainage solutions should complement conventional engineering.
10. Adi Ganga should be managed through an integrated River–Groundwater–Wetland–Urban Planning Framework.

Long-Term Recommendation

The ultimate goal should be to transform Adi Ganga from a polluted urban drain into a functioning blue-green ecological corridor, capable of contributing to flood resilience, groundwater protection, biodiversity, cultural heritage and environmental sustainability.

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