The Changing Paradigm of Urban Riverfronts: The Role of Rivers in Mitigation of Urban Heat Island Effect and Climate Change – A Case Study of Delhi

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Abstract
Human settlements have always been strongly linked to and evolved around rivers. Ancient civilisations such as Egyptian, Mesopotamian etc. all flourished near rivers. But today, due to anthropogenic activities, rivers are drying and moving towards extinction. It is very important to identify the crucial role of rivers in sustaining the well-being of humans as well as other biodiversities. The study aims to examine the role of rivers in the urban environment and to propose a prototype for an effective riverfront that maintains a balance in the ecosystem. This has been done by addressing the challenges which urban rivers endure, and suggest aids in reducing the effects of 'Urban Heat Islands' (UHI) in cities in general, and in the study area in particular. At present, cities along the Ganga basin are in a dilapidated stage and unorganised, which attracts climate vulnerability. UHI is one of the causes for increasing the demand for artificial cooling and discourages the culture of local interaction. The present study will focus on creating or restoring a riverfront that promotes a 'social connection' between the river and built-up interface and evaluates the ecosystem benefits. The proposal shows that the model has potential for creating value of approximately INR 60 crore in the initial two plus years. This study will help the city administration and government to take proactive steps in future and save mankind from the ill effects of climate change.

Key words: Land Surface Temperature (LST), Ecosystem Valuation, Urban Heat Island (UHI) Effect, Climate Change, Riverfront Development (RFD)

Introduction

Human beings as part of a large community are but a small part of the ecosystem in a biome which in turn is a part of the largest biosphere that helps in maintaining ecological balance. Rivers being a vital part of the ecosystem sustain millions of lives that help in maintaining the ecological balance. The river connects the culture, livelihood, environment, economy to the people and creates value. This case study has been done to understand the relationship between the changing river course of the Yamuna with the dynamic city of Delhi and its people by addressing the challenges which urban rivers endure and to propose a prototype for an effective riverfront.

There are many challenges that rivers are facing today due to urbanisation. Due to activities such as deforestation, dumping industrial waste, sewage waste into rivers, river pollution, diverting the river water or obstructing its flow by building various barriers, the overall ecological balance has been affected leading to the drying up of rivers and their moving towards extinction. The growth of cities near rivers with the fast pace of urbanisation has put immense pressure on limited natural resources like land, forests, rivers etc. The continuous depletion of resources has outpaced the regenerative capacity which has disturbed the natural healing process of nature and is leading to the phenomenon of climate change. As a result, the fast-changing land cover due to urbanisation is responsible for the 'urban heat island' effect. The riparian zone along the rivers is part of floodplains that acts as a buffer between city and river by storing excess water during flood situations and maintaining the ground water level. This is slowly being encroached upon by development activities leading to disasters.

The study by Sharma & Dikshit (2016) states that changes in the use of land such as replacing the pervious layer with an impervious layer have a direct impact on the overall carbon sink. Another study by Voogt and Oke (2003) has studied UHI relative to its size in terms of population in a city. This study gives us the relationship between the changing land cover and carbon sink which is an important factor in the discussion of climate change. Also, the land use and land cover change (LULCC) is associated with increasing population and the UHI effect. The present study is done in the context of Delhi and it forecasts a scenario where Delhi's developing populace and changing landscape is probably going to encounter a higher UHI impact. Another study in the context of Delhi by Mohan M., Kikegawa Y., Gurjar B., and Bhati S. (2013) observed that the dampness present on the green cover surfaces has a lower temperature, indicating the role played by healthy green vegetation in balancing the temperature. It also observed that the open regions (without trees) have less distinction among ambient and skin temperature because of the absence of impenetrable and canopy layers (trees) which is closely identified with LULCC, and is responsible for unbalancing the ecosystem. The implications of anthropogenic activities are economically very serious. This has led to the extinction of many bio-diversities and placed many others in the critically endangered category.

Climatic impacts have more harmful results, for example, restructuring of ecological systems, inhibited growth of creatures and plants, expansion in pandemic like situations, increase in human medical problems, and so forth, as per the study by Veena, Parammasivam and Venkatesh (2020). It was also noted that variations in a population's age structure can indeed lead to economic growth potential, especially when the working-age population (15 to 64 years) is larger than the non-working-age population. It refers to the ongoing population growth, as well as the trend toward increasing savings and investment, which can help drive the creation of additional goods and services using non-renewable energy sources (in developing nations where clean technologies are not readily available). The use of non-renewable sources for energy further exemplifies the climate change phenomenon. If rivers disappear or degrade, the dependent population will lose its cultural identity and way of life resulting in alienation, loss of livelihood opportunities, loss of biodiversity, leading to economic and environmental implications. The environmental implications are larger and will result in the extinction of biodiversity, ecosystem services, and at later stages human beings themselves. The revival of rivers will help in reimagining the urban river and re-establishing its social, economic, cultural, environmental connection to its people. The benefits will help in re-acquainting environmental loss which in turn will help in reviving rivers and realising economic potential through ecosystem services.

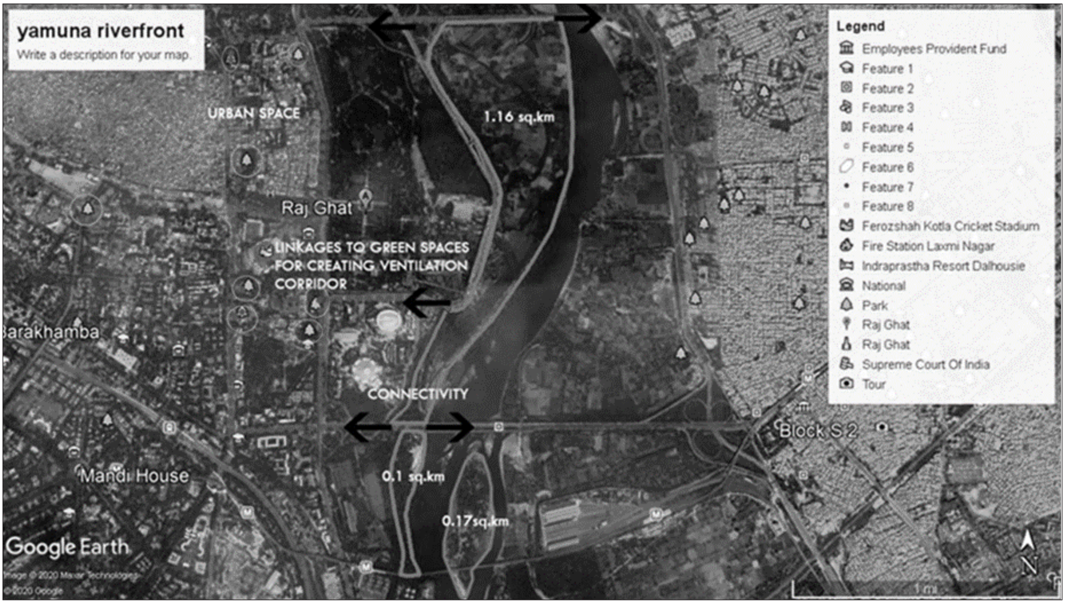
In the present context of Delhi on the Yamuna bank, the observations made by Sharma and Kansal (2011) have shown that 100 per cent divergence of the Yamuna River for water purposes in Delhi leads to a declining groundwater table. This decreasing discharge of groundwater has a substantial impact in the long term on agriculture, biodiversity, soil fertility, water flow, water volume, river pollution and the overall ecosystem. The divergence of water also has effects on the Albedo with the overall energy balance being disturbed. With disturbance in the water cycle and land use cover, the city is experiencing the UHI effect. A study by Masson-Delmotte,V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.) (2018), found that globally there is an overall increase in temperature by 1-2 degrees. Other observations concerning the heat index of Delhi specifically, indicate immediate danger throughout the late spring (March-June) and rainstorm (July-September) seasons since 2016 according to the study by Somvanshi A. (2019). The latter also shows the relationship between increasing air pollution and increasing temperature. The study has additionally presumed that this factor has necessitated raising power interest by 1,856 GWh over the base power necessity of the city with a relating expansion in CO2 discharges by 1.52 million tons. The study also emphasises increasing human deaths resulting from the soaring heat index killing thousands of people every year.

In the present context, the research was carried out with the help of satellite data to study the changing river course and urbanisation trend over 30 years to identify the urban heat island effect. Also, the data has helped in establishing the connection between increasing built-up activity with decreasing green cover and other LULC over the years, which has immensely helped in designing a prototype for ecological riverfront development. The analysis has brought clarity to the issue regarding mitigation efforts needed in this direction. The present study will help in identifying the reasons for a shrinking river and detached riverfront and proposing a design which caters to the challenges of the urban heat island effect in cities and climate change in the long term. The prototype addresses the river's waning condition by addressing aesthetic (city identity), social, climatic, economic, and environmental challenges by creating spaces for social connection, addressing climatic aspects with the creation of a ventilation corridor, addressing environmental aspects with various design approaches that add value to the ecosystem and generate economic value, and achieving an effective riverfront development. This research and design will provide policymakers with a paradigm study for effective riverfront development from an ecological standpoint.

Site Context and Background

The Yamuna River is the largest tributary of the Ganges River. It is also considered a sacred river in India. The source of the Yamuna is located at an average elevation of about 6,387 meters above sea level in the Uttarkashi region, starting from the Yamunotri glacier near the summit of Bander Punch in the Mussourie mountains at the bottom of the Himalayas. The main tributaries of this river are Tons, Betwa, Chambal, Ken and Sindh, which together account for 70.9 per cent of the basin area, and the remaining 29.1 per cent constitutes the direct drainage of the main river and smaller tributaries. Depending on the region, the Yamuna River Basin accounts for 40.2 per cent of the Ganges River Basin and 10.7 per cent of the country as per the study by Sharma and Kansal (2011). During the 1,370 kilometre journey from Yamunotri (birthplace) to the sea, the Delhi section of the Yamuna River occupies only 22 kilometres. Although it only represents 2 per cent of the length of the basin, it contributes more than 80 per cent to the pollutant load of the entire stretch of the river as per the study by the Delhi Urban Art Commission (DUAC, 2015).

Figure 1: Study Area Site for Yamuna Riverfront



Source: Google Earth (Access date 28-10-2020)

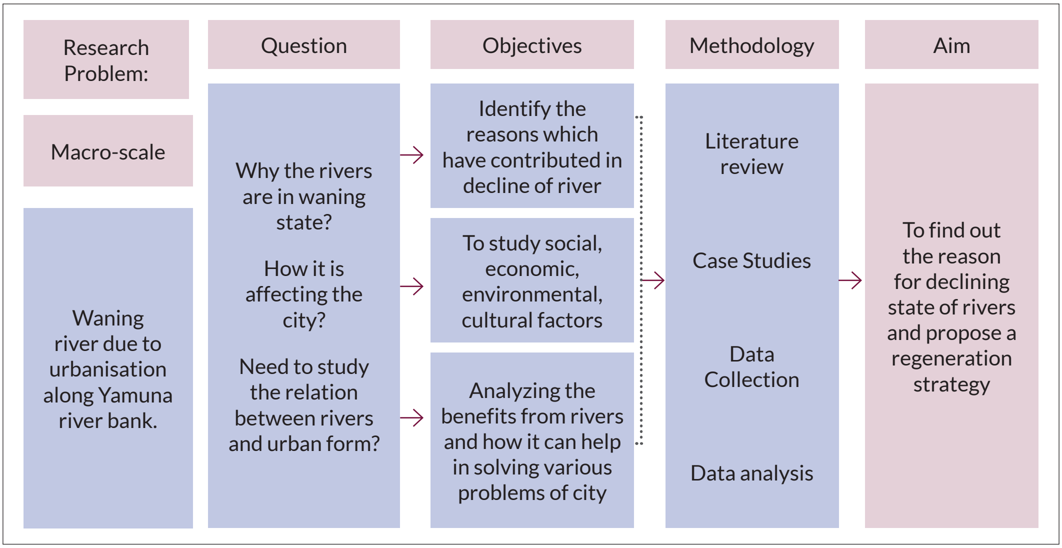
The site is already under proposal for Yamuna riverfront development by Delhi Development Authority (DDA). However, it does not address the concerns of the UHI Effect and the role the river can play in reducing it by establishing a social connection culturally through the positioning of green spaces. This can be done by connecting it with a proposed ventilation corridor which will result in environmental benefits and subsequent economic benefits. The economic benefits will help in the self-sustainable riverfront development model in the long term and the positive environmental impact will help in restoring the degraded ecosystem due to anthropogenic activities. This study will help policymakers with the paradigm case study for effective riverfront development from an ecological approach. These factors were missing in various proposals given till now for Yamuna riverfront development. The present context has potential for creating a ventilation corridor and also has heritage value (Feroz Shah Kotla and Khooni Darwaza) lying in the close proximity to selected site which will help in creating an identity for the riverfront. The agricultural land in existing patch of the site can be useful in creating value for the environment. Lastly, evaluating the addition of green spaces through economic appraisal will create value for ecosystem services that will help government, policymakers in understanding the ecological approach benefits from the economic angle. Further, the replication of the model will create awareness among people and more people participation will make this sustainable model a community project.

Study Methodology

The research was carried out at two scales: macro and micro. At the macro level, the research problem was focused on understanding the shrinking condition of the river and various other factors responsible for causing it in the context of the river covering the entire Delhi region. At the micro scale, it addressed the forgotten and detached riverbank by proposing a regenerative strategy covering a radius of about 5 km (area of 25 sq. km) from the site as shown in Figure 2. After analysis through various primary and secondary studies, an effective riverfront prototype was proposed specifically to this context.

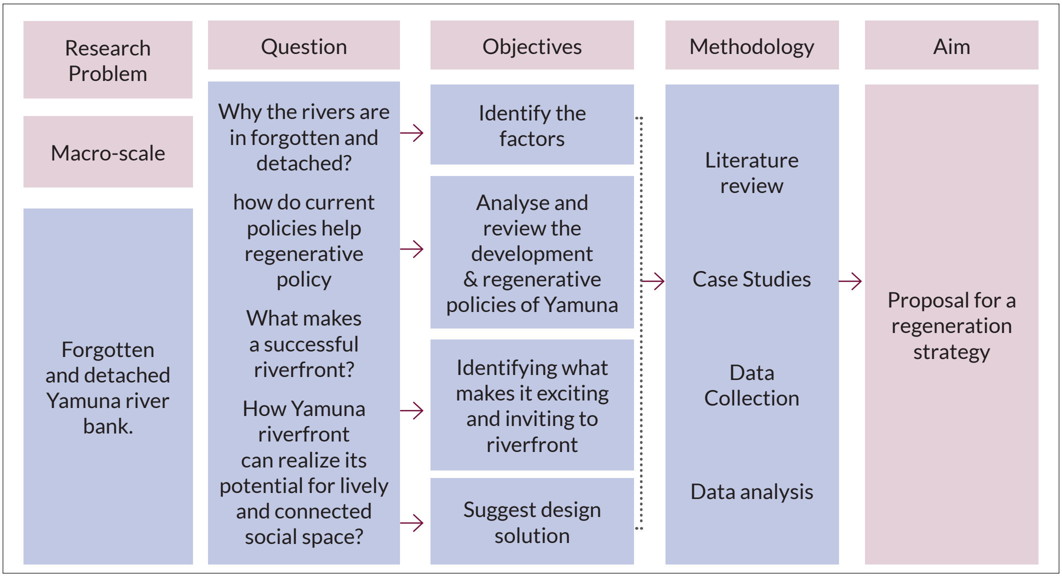
To understand the scenario at the macro level, the satellite images were used for analysing the land cover change, preparation of land surface temperature maps and detecting UHI and overall change of temperature across different land use, flood mapping, Normalised Difference Vegetation Index (NDVI), Normalised Difference Built-up Index (NDBI) maps, etc. To perform analysis at the micro scale, formal and informal surveys were conducted, site analysis was done, a land use map was prepared, and analysis like computational fluid dynamics was observed for this location as shown in Figure 3. The secondary data over the years for different places in Delhi was collected, which included statistics for air pollution, heatwaves, the number of deaths due to air pollution, flooding history, energy consumption and its relation to UHI, identifying the wind corridors near rivers and their effects in reducing UHI effect, the contribution of vegetation in the context of ecology and economy, and other data specific for the Delhi region. This data has immensely helped in building a prototype ecological riverfront addressing the context-specific challenges of the study area.

Figure 2: Macroscale Research Analysis



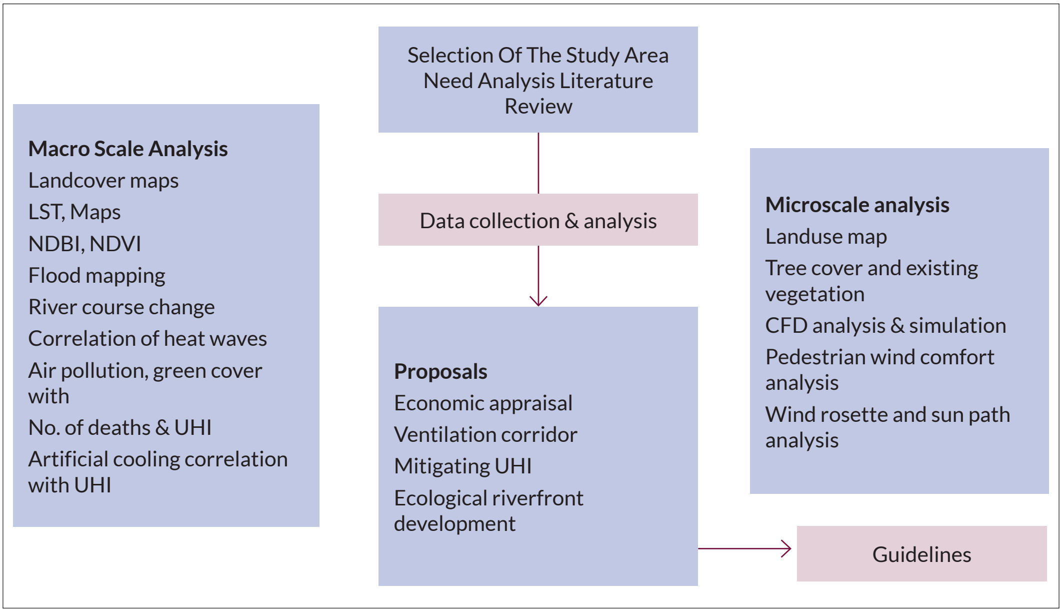
Source: Authors

Figure 3: Microscale Research Analysis



Source: Authors

Figure 4: Study Methodology



Source: Authors

Data Collection

The data was collected for the past 30 years to understand the climate behaviour by analysing the UHI effect, rainfall pattern, heat index, land cover change, air pollution and deaths due to it, UHI and its correlation with artificial cooling specific to major issues concerned with runoff water, floods, heating of the areta. The vulnerability analysis was carried out based on the existing data in GIS, which helped in computing the economic loss to the city. For the preparation of surface temperature maps and land cover maps, Landsat imagery was used for the same month (May), same date (14 May) and different years (1990, 2000, 2010, 2020). Similarly, the analysis through secondary studies indicated the ill effects of UHI on local people by analysing the health data as UHI also worsens the effects of some natural events like heat waves. Primary data was collected by carrying out site surveys, questionnaire surveys, informal questioning. Secondary data was collected from multiple development plans. The data collected through various literature has helped in analyzing the groundwater potential, decadal and annual fluctuation in groundwater, depletion of groundwater, loss of floodplains, change in seasonal and annual rainfall patterns, drought frequency, heat index correlation with the rise in electricity demands and the increasing number of deaths due to it, increasing heat stress and air pollution in the cities and its correlation with UHI, and the overall carbon footprint of the city.

The data collection for the research work is carried out at macro and micro scale to understand the situation holistically. For collecting primary data in a proper format, a questionnaire was generated which included questions investigating the perception of riverfront development in Delhi. The survey was conducted on May 20th, 2021 online by getting information from inhabitants of Delhi communities. A total of 49 (simple random sampling) responses were recorded to understand the perception of people about RFD and River from Delhi locals through online mode, while offline inputs (from those living along the river) were acquired by visiting nearby slums. Because all slums around the river could not be covered due to COVID-19 constraints, the slums that fell under the micro scale (25 sq. km) were considered. Forty responses were recorded on site to understand the viewpoint of the informal sector working in the Indraprastha area, and were captured through a Google questionnaire form for holistic analysis.

Data Analysis

Data analysis was performed to better understand the area. Few factors cannot be judged by direct observation, and more graphics and statistics need to be analysed to relate them to other factors. The primary and secondary data collected were analysed to propose a regenerative strategy for the Yamuna river bank.

Primary Survey Results

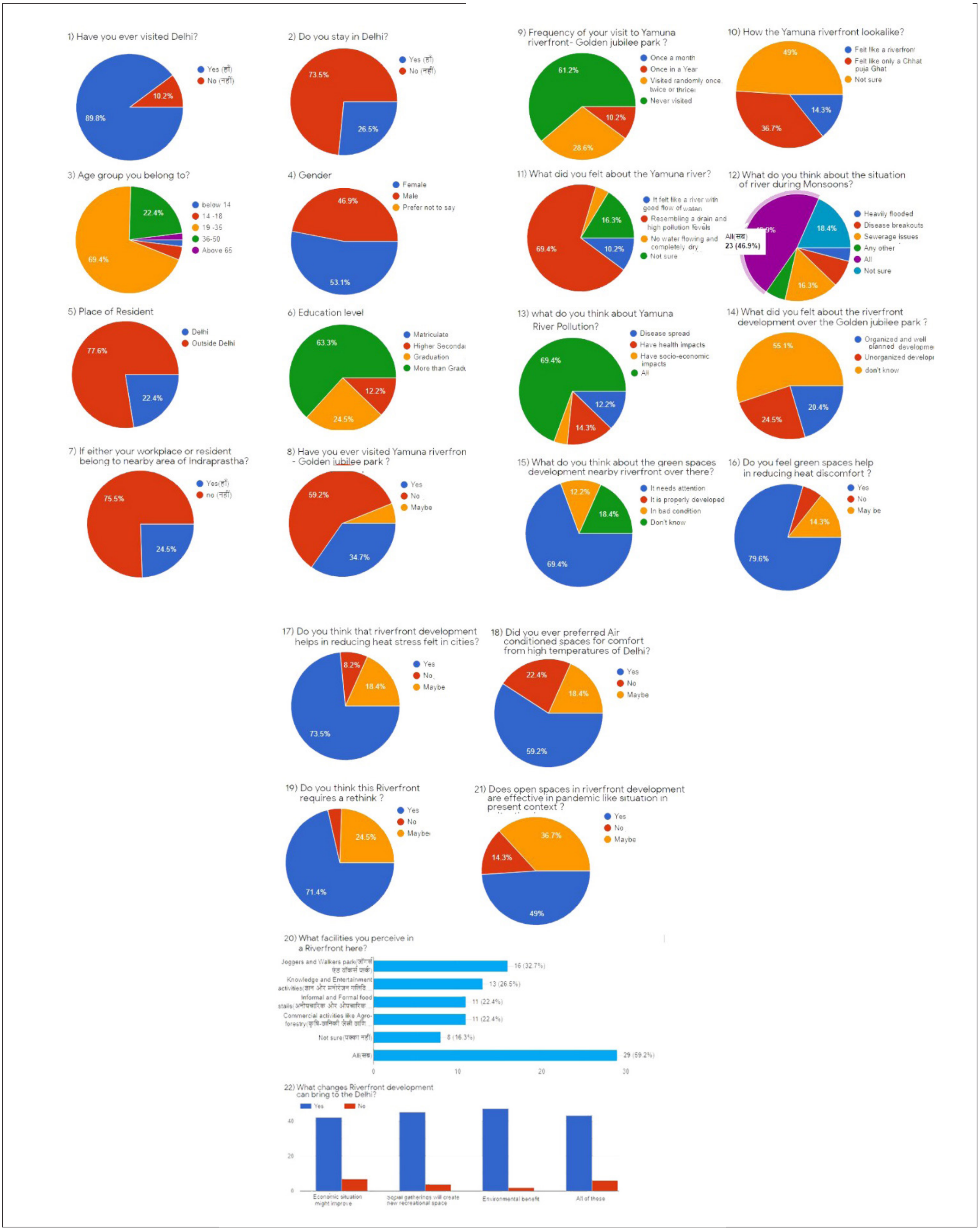
The primary data was collected with the help of a questionnaire to understand the public perception of riverfront development (RFD). The formal survey aimed to analyse the perception of the Delhi localities and how they connect with the river.

The survey result shows the positive perception of people for riverfront development along with environmental concerns as they connect strongly with the river's deteriorating condition and river pollution. It was an attempt to understand the perception of regional localities living near this area and the frequency of the inhabitants' visits to the river. The responses recorded show that 69.4 per cent were not able to relate to it as a river but as a drain. The perception of 71.4 per cent was in favour of rethinking riverfront development. The survey also tried to capture the facilities the people are looking forward to in riverfront development to capture the social and economic angles in order to propose a prototype for this area as the site is already under proposal for RFD. Also, the survey showed that 74.5 per cent of the people felt a thermal comfort as compared to the city due to greener areas in the vicinity. The survey has helped in understanding the potential of the site to be developed, along with the constraints.

Secondary Survey

The satellite images were downloaded for the years 1990, 2000, 2010, 2020 from the USGS website from the LANDSAT 5 TM, LANDSAT 8 OLI sensors of the study area for date 14-05-2020 and were used for analysing LST, NDVI, and NDBI and were classified into five classes (agriculture, bare soil, vegetation, built-up areas, water body/river for LULCC detection. The entire process is described below in detail. The maps were corrected with the Kappa accuracy assessment method to avoid any discrepancies, showing 75 per cent results. The land cover change analysis was performed in the GIS through dissolve function and it showed the maximum change in built-up areas, agriculture and vegetation land use. Building activity from the 1990s to 2020s increased from 16.43 per cent to 50.33 per cent for overall Delhi.

Figure 5: Perception of Surveyed Individuals about River, Green Spaces and Riverfront Development, 2021



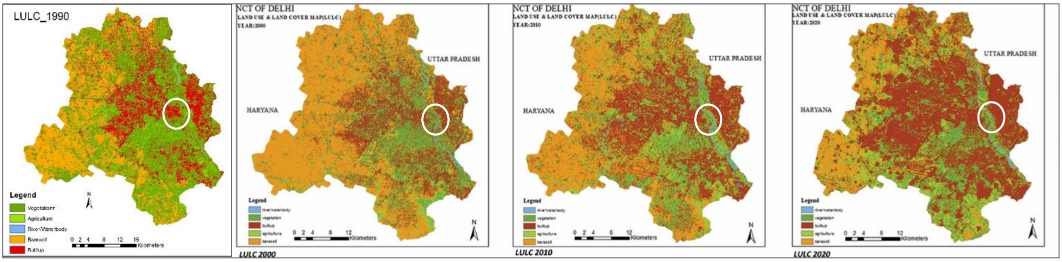
Source: Primary Survey, 20 May, 2021

Vegetation area decreased from 53.18 per cent to 13.79 per cent in 30 years. Agriculture activity increased from 4 per cent to 18 per cent. This suggests divergence of vegetative land for built-up and agriculture activities. Apart from this, the water body surfaces have shown a fluctuation in increasing or decreasing trend. After the land cover change analysis, the same maps were analysed for the five classes (agriculture, bare soil, vegetation, built-up areas, and water body/river) for land surface temperature change for the last 30 years.

Land Surface Temperature (LST) represents the temperature of the ground surface and is one of the important parameters that affects the energy balance of the ground surface, the local climate, and the exchange of heat flux and energy.

i) Land cover change analysis from 1990-2020

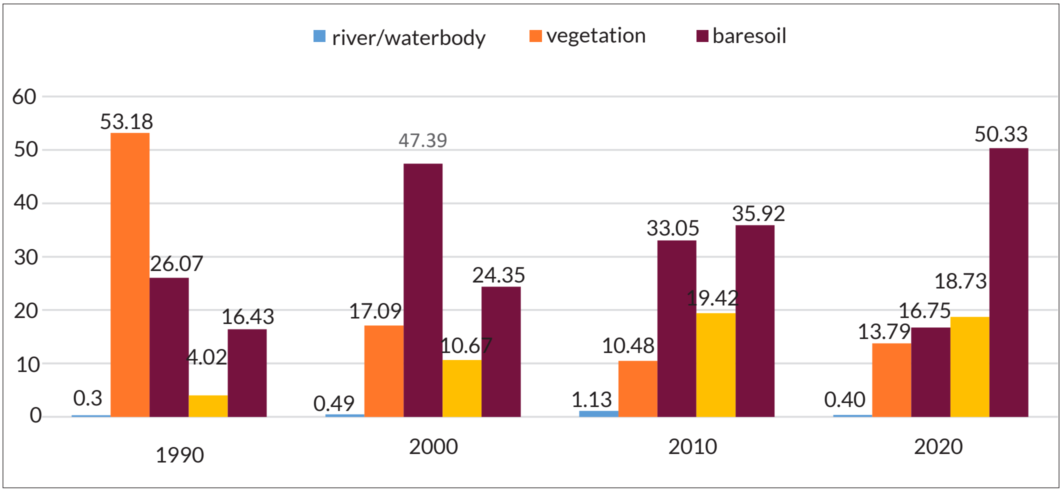
Figure 6: LULCC Change Detection, Indraprastha Area, Delhi



Note: Site of Microscale Study, Indraprastha area (25 sq. km)

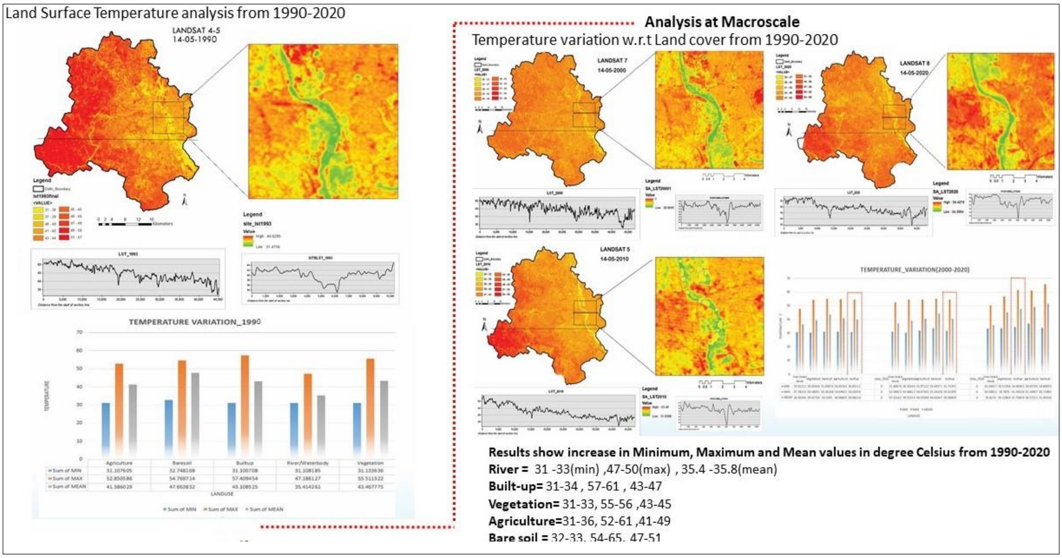
Source: USGS website, Landsat Imaginary 5 TM, LANDSAT 8 OLI sensors

Figure 7: Change (in %) in Land Use and Land Cover, Indraprastha Area, Delhi



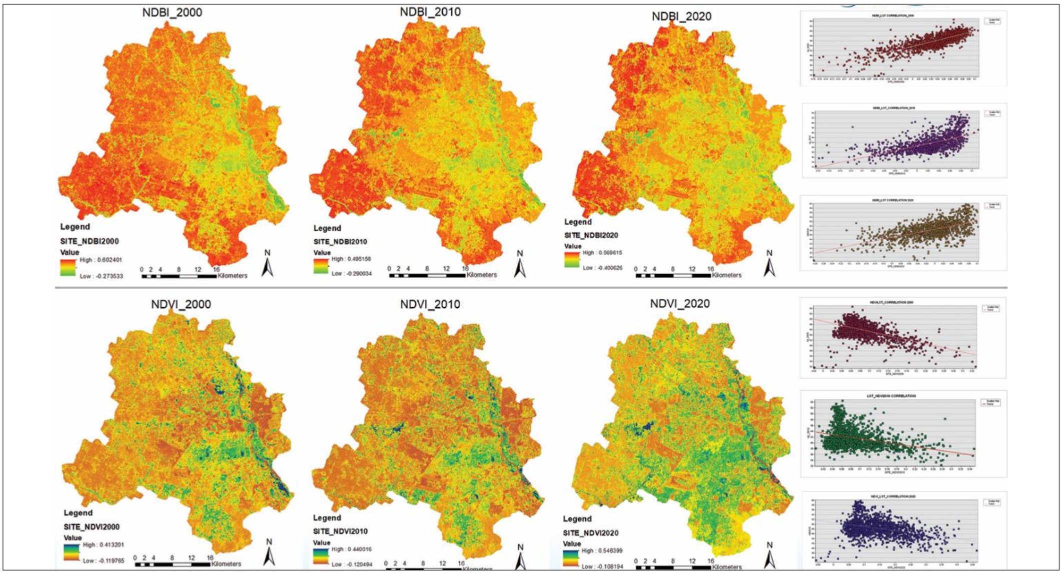
Source: USGS website, Landsat Imaginary 5 TM, LANDSAT 8 OLI sensors

Figure 8: Land Surface Temperature Maps for Delhi (14th May 1990-2020) and the Corresponding LULCC



Source: USGS website, Landsat Imaginary 5 TM, LANDSAT 8 OLI sensors

Figure 9: NDBI and NDVI Maps for Delhi (14th May 1990-2020) and Corresponding LST and LULCC



Source: USGS website, Landsat Imaginary 5 TM, LANDSAT 8 OLI sensors

The NDVI and NDBI analysis was performed further to confirm the effect that built-up activities are having on escalation of temperature whereas vegetation, river/water bodies help in pacifying the rise of temperature.

ii) Results

The results show an increase in minimum, maximum and mean temperature for the last 30 years due to land cover change.

Table 1: Results of Temperature Change Due to Land Cover Change

Land use	Temperature		
	Minimum range (degree Celsius)	Maximum range (degree Celsius)	Mean range (degree Celsius)
River/ water body	31- 33	47-50	35.4-35.8
Built-up	31-34	57-61	43-47
Vegetation	31-33	55-56	43-45
Agriculture	31-36	52-61	41-49
Bare soil	32-33	54-65	47-51

Source: Calculated by Authors using ArcGIS sectional analysis

The NDBI correlation analysis shows a positive scatter plot graph indicating the rise of temperature with increasing built-up activity. The NDVI correlation analysis shows a negative correlation of land surface temperature with vegetation and water surface indicating that vegetation, water bodies and rivers play a role in cooling the spaces.

Limitations

The CFD analysis which helps in determining the wind direction and wind velocity at the local scale was not performed due to time constraints and COVID restrictions for the site visit. It would have helped in confirming and strengthening the proposal results at the micro level.

Results and Discussion

Detection of changes helps to quantitatively analyse past impacts of events by applying Remote Sensing information and determining changes in the properties of LULCs referenced from various satellite data sets. After analysing changes at the macro level and understanding different factors responsible for river deterioration, the study was focused on the micro scale for proposing a regenerative strategy by proposing an effective riverfront development plan. The confusion matrix was prepared for the site covering the 5 km radius (covering approx 25 sq. km area) to understand the land cover changes surrounding the site from 2000 to 2020.

Table 2: Confusion Matrix for 25 Sq. Km Riverfront Development Site

Confusion Matrix Agriculture		Area(ha)_2020					
		Bare soil	Built up	River/ Waterbody	Vegetation	Total	
Area(ha) in 2000	Agriculture	3872.25548	1262.64	6705.92	24.78	3948.70	15814.30
	Bare soil	17144.8263	21190.10	26679.37	11.03	4638.51	69663.84
	Built up	3206.56706	1049.03	28602.69	49.35	3292.24	36199.87
	River/ Waterbody	53.206563	139.05	157.74	243.31	140.77	734.067
	Vegetation	3407.33426	1121.43	12253.06	255.63	8357.12	25394.59
	Total	27684.1896	24762.26	74398.78	584.10	20377.34	147806.7

Source: Authors' (ArcGIS raster calculations of land cover change)

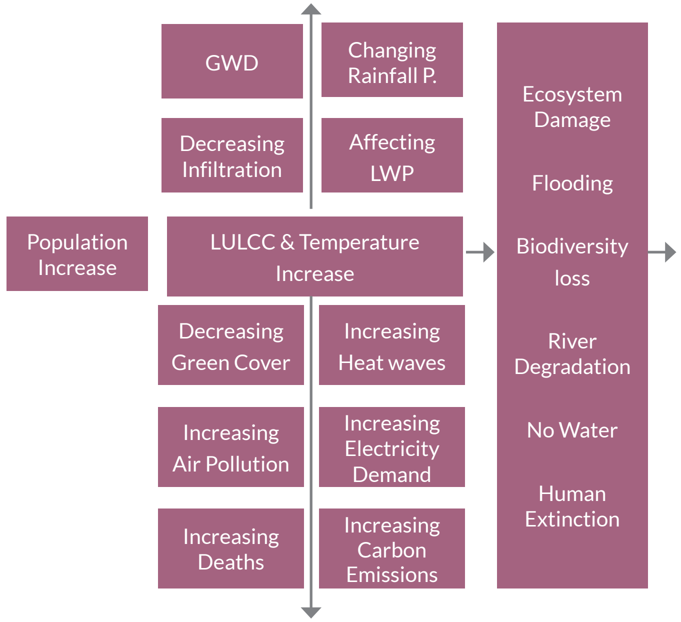
The confusion matrix shows the area change inland cover from the year 2000 to 2020. Out of the 15,814 ha that was agriculture area in 2000, 3872.25 ha still remained agriculture area in 2020 but 1262 ha was converted to bare soil/rocks, and the rest to vegetation and built-up Area. Out of 25,394 ha in year 2000, vegetation area lost mainly to agriculture, bare soil/rocks and built-up area, and retained 3407.33 ha of the total in 2020. Built-up area increased from 36,199 ha in 2000 to 74,398 ha in 2020. It retained 28,602 ha of it and was mainly replaced by agriculture and Bare soil/rocks. The category which built-up area mainly replaced in 2020 was bare soil and vegetation (12,253 ha). This study elucidates the importance of integrating GIS with remote sensing studies to detect changes in local land cover/land use to provide important information about spatial distribution as well as the changing nature of land cover. The water category in 2020 retained only 243 ha of the total 734 ha in 2000.

The temperature variation across different land use in LST shows the increase in minimum and maximum values of temperature. This indicates the UHI effect. Moreover, the temperature across built-up area is rapidly changing, indicating the change of land cover leading to a rise in temperature. To validate the above change taking place in the city of Delhi, the average ambient temperature of the city was compared with this rising temperature to analyse the difference. The ambient temperature in any case has not extended beyond 41-42 degrees Celsius overall for Delhi, whereas the LST shows the variation observed in temperature difference for different land cover in more than two decades.

For NDVI, the Scatter Plot was plotted to analyse the relationship between NDVI and LST. It shows a Negative correlation between NDVI and LST. It indicates that the less vegetative area is associated with high temperature whereas the high vegetation area is associated with low temperature. Thus, vegetation helps in keeping the temperature low. Similarly, for NDBI, the Scatter Plot was plotted to analyse the relationship between NDBI and LST. It shows a Positive correlation between NDBI and LST. It indicates that the high built-up area is associated with high temperature (in the city too) whereas the low built-up area is associated with low temperature.

The above maps from the year 1990 to 2020 indicate the increase in built-up area. This increase has changed the land use pattern. Pervious open land has been converted to an impervious layer. This has decreased the infiltration rates to the groundwater table. It was observed that the area under vegetation also decreased indicating less evapo-transpiration. All this has contributed to raising the overall temperature of the city in general. This suggests that in future the temperature will further increase causing discomfort to all living beings along with various other consequences.

Figure 10: Consequences of LULCC and UHI Effect on Rivers



Source: Authors

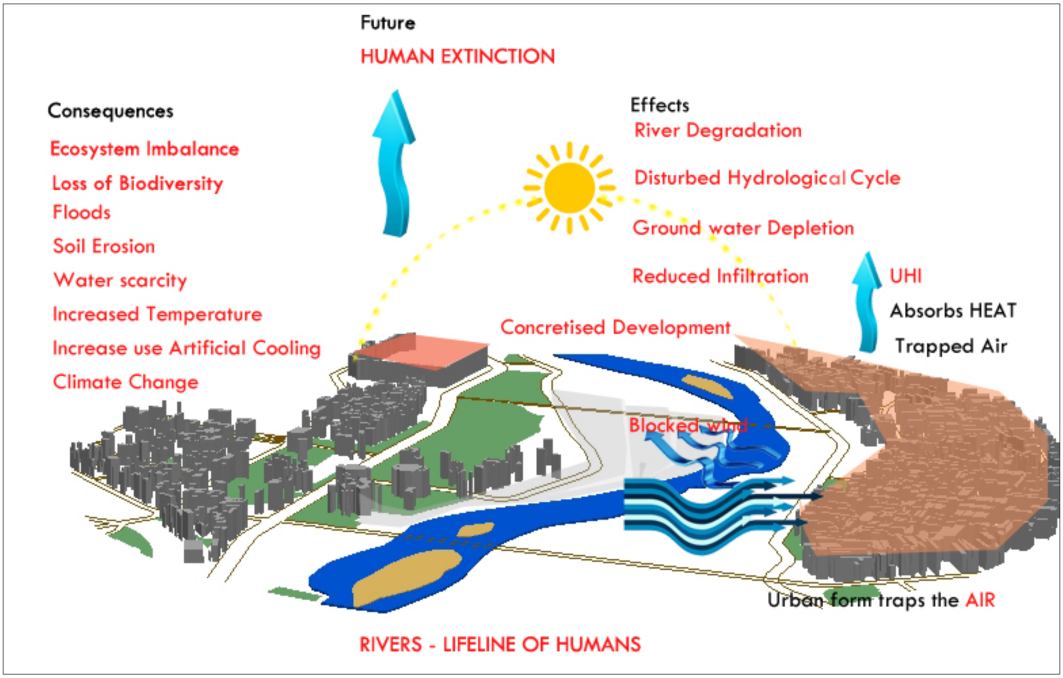
Urbanisation is increasing because of the rising population leading to LULCC and temperature increase has many consequences as shown in the above Figure 10. The LULCC leads to decreasing green cover which intensifies air pollution and is one of the causes for increasing deaths in Delhi as per the observation of the department-related standing committee on Science & Technology, Environment & Forests (2018). The temperature increase adds to the heatwaves which drive the demand for artificial cooling, leading to an increase in carbon emissions.

The LULCC, with more and more addition of impervious layers due to increasing population leads to decreasing infiltration rates which exacerbate groundwater depletion. All these processes disturb the natural hydrological cycle vertically with the atmosphere and horizontally with the ground leading to changing local weather patterns, which further affects rainfall intensity and its distribution. This has wider implications on the health of the ecosystem and contributes to the degradation of the rivers. The situation currently is such that there is no water flowing through the rivers in the dry season and only sewerage flows through it.

Recommendations

The regenerative strategy is proposed to revive the ecosystem. The design concept was worked out on the principle of a water-sensitive design strategy, which in the long term will help in reviving the ecosystem.

Figure 11: 3D View of Site in Business as Usual (BAU) Scenario

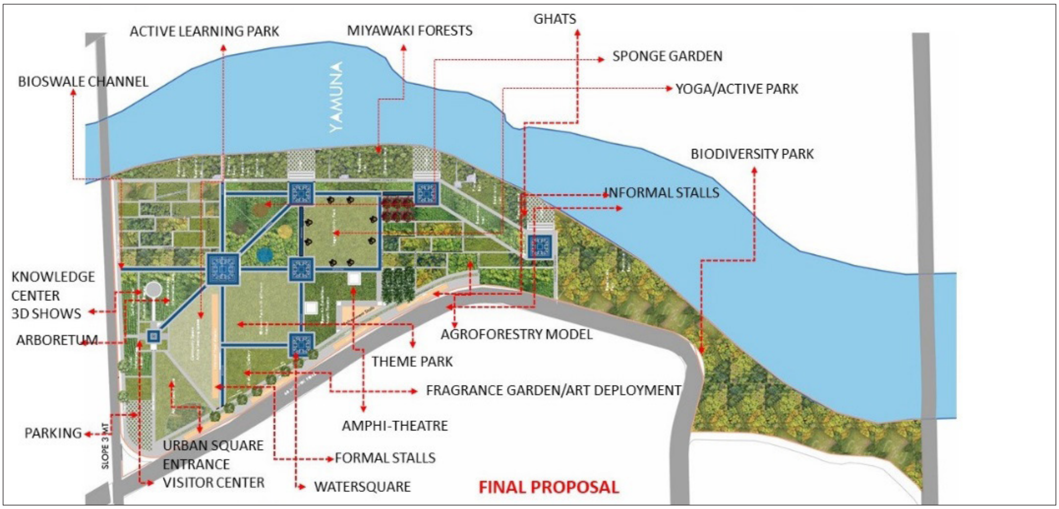


Source: Delhi Master Plan 2021

Figure 12: Proposed Site (Indraprastha) through an Ecological Approach

Source: Delhi Master Plan 2021

Figure 13: Final Proposal for Riverfront Development



Source: Delhi Master Plan 2021

The 3D visual of the site explains the BAU scenario of concretised development and the consequences leading to river degradation. But if the site is developed as a ventilation corridor as shown in Figures 11 and 12 it helps in pushing the cool river breezes towards the core of the city. These breezes from the river help in connecting the river to the city physically and mentally by establishing a social connection. The ecological approach to the riverfront development further helps in realising environmental, cultural and economic value.

The final proposal for a regenerative strategy was proposed keeping in mind the potential of the site. The macro- and micro-level analysis in GIS software further helped in the determination of existing water streams and headwaters in the site which play an important role in water storage and maintaining a continuous flow of water in the rivers. The concept was to establish a connection by addressing Climatic, Environmental, Economic, Cultural and Aesthetic factors which address a water sensitive based regenerative strategy. The proposal will help in mitigation of the UHI effect by building a ventilation corridor (the RFD is conceived as a form that will help in promoting the cool breezes from rivers to the city core and in establishing a connection). The water streams helped in identifying ideal locations for urban squares, water squares and other landscape activities around the riverfront. The design has been proposed keeping into consideration the strategies of Master Plan Delhi 2041 and differentiation proposed by DDA around rivers in the sensitive, protected and interactive zones, and accordingly activities are proposed. The site falls under Zone O, an interactive zone as a recreational zone for development. The proposal addresses the ‘No Water’ scenario in rivers and proposes recharging of *kunds* which will help in situation improvement in the long term. The theme for the riverfront development was based on the traditional architecture in order to give it character, and where people can connect with the architecture and tales of the river Yamuna. The motive was to capture responsible behaviour patterns of people through sensitisation and to increase awareness towards maintenance of the ecosystem.

a. **Economic Appraisal:** To capture the economic value in the proposed model, different strategies were employed as shown in Table 3.

i. Total economic value of riverfront development

Table 3: Total Economic Value Generated in Initial Years

Ecosystem service	Type of service	Valuation technique	Total value (INR) (crore/ year)	% Contribution of total economic value
Conservation	Non-use value	Contingent valuation	27	43. 3
Education and research	Indirect-use value	Market price	1.4	2.25
Carbon sequestration	Indirect-use value	Market price	7.4	11.89
Recreational and cultural	Indirect-use value	Individual travel cost method	12.4	19.9
Water potential Value		Market price	14	22.5
Total			62.2 cr	100
Surrogate value of land	Non-use value	Opportunity cost	25 cr (one time cost)	t
The land value of the Delhi zoo	Non-use value	Market price (benefit transfer)	12281.5 cr (one time cost)	

Source: Referred and modified from Economic Valuation of Ecosystem Services, National Zoological Park, New Delhi, 2020.

The detailed calculation for deriving these values has been discussed below. The values for education and research and environmental conservation were derived from the report[1] of the survey done for the National Zoological Park by TERI, New Delhi, and Central Zoo Authority in the vicinity of radius 1 km and accordingly, it was extrapolated for the entire population.

ii. To calibrate the water potential added to the site, the following method was used:

Table 4: Water Potential Value

Proposal for Riverfront Development			
Class	Stock added (ha)	Storage potential	water value
Agroforestry	32.4042	171105	4510327.8
Urban Forest (Biodiversity)	36.1082	186660	4920357.6
Water Estimates (Rainwater Harvesting)			9430685.4

Source: Authors' (calculations as per design area).

[1]*Report on Economic Valuation of Ecosystem Services, National Zoological Park, New Delhi, 2020.*

Monetary Potential

The water tariff rate per 1000 liters (1 cu.m) in Delhi is 26.36. For Delhi, peak hourly rainfall is 90 mm (based on 25-year frequency) and 15 minutes peak rainfall is between approximately 22.5 mm/hr and 25 mm/hr, according to Central Ground Water Board (CGWB) norms.

For proposed recharge kund = Large kund = 10368 x 0.025 x 0.85 = 220.3 cu.m; Small kund = 5950 x 3 = 17,850 = 379.3 cu.m. Total A = 599.6 cu. m of water stored.

Design of recharge trench: Assuming a void ratio of 0.5, the required capacity of a recharged tank is 29,073 x 0.025 x 0.85 /0.5 = 1235.6 cu m = Total B. TOTAL = A+B = 1835.2 cu.m.

Annual water harvesting potential: Delhi average rainfall = 611 mm. Total site area (1000,000) x 0.6 x 0.85 = 518,500 cu. m x 26.36 = 13667660/- (13 crore).

iii. Environment conservation (willingness to pay)

Table 5: Environmental Conservation Valuation

Range (INR)	Percentage of people willing to pay	Number of people	Average value (INR)	Value of biodiversity conservation (INR)
free	10	330,096		
0-50	59	2,025,589	23	46588547
50-100	14	480,140	93	44653020
100-200	10	360,105	150	54015750
200-500	4	150,044	440	66019360
500-above	3	90,026	700	63018200
Total				274294877=27 cr

Source: Referred and modified to the context from report on Economic Valuation of Ecosystem Services, National Zoological Park, New Delhi, 2020.

The surrogate value of the land is circle rate x area. The circle rate for the riverfront location is 106400/sq. m (Indraprastha). The land value of the site is INR 12281.5 crore. The surrogate value of land is estimated to be around INR 250,000,000 or INR 25 crore. The values are directly assumed from the survey done for the National Zoological Park which estimated ecosystem services valuation after the park was made. The zoological park lies in the influence zone of 1 km of the site and hence a minimum of 5 per cent visitors was assumed to be visiting this site after it was completed.

iv. ***Education and research (willingness to pay):*** As per the survey of the National Zoological Park, lying in the influence zone of Riverfront Development, it was assumed if 5 per cent tourists out of the total tourists coming to the National Zoological Park visit this riverfront, it would have the potential of generating a value of INR 14 crore approximately.

Table 6: Education and Research Valuation

% of people subscribed to wildlife and environmental information programme	Total assumption of visitors	Value incurred annually	Annual cost (INR) invested by visitors
4% (Offline)	100000	INR 2333	9332000
72%(Online)		INR 75.11	5472000
24%(None)			0
Totalt			14.804000 cr

Source: Referred and modified to the context from report on Economic Valuation of Ecosystem Services, National Zoological Park, New Delhi, 2020.

Carbon Sequestration: The rate of carbon sequestration depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted, and the density of the wood of the trees. It is greatest in the younger stages of tree growth, between 20 to 50 years. The native species were identified for the site and above breast diameter was identified. The following steps were followed as per the study by Sharma Richa et al. (2020).

Step 1: Tree Height and Girth at Breast Height (GBH)

Step 2: Estimation of Above-Ground and Below-Ground Biomass (AGB and BGB)
AGB = 34.4703 − 8.0671D + 0.6589D2 (1) where D is the DBH (cm). BGB = AGB × (15/100)

Step 3: Estimation of Total Biomass (TB) = Total Biomass = AGB + BGB

Step 4: Estimation of Carbon Content = 0.5 × Total Biomass

Step 5: CO2 equivalent is then calculated using the equation given below : CO2 (eq.) = (carbon content × 44)/12

The results of this study as shown in Table 7 illuminate the value of urban trees as well as their aesthetics, which mitigate the effects of climate change at the local level. It is important to study the potential for carbon sequestration in the centre of the city to understand and emphasise the role of urban green spaces in offsetting carbon dioxide emissions at the regional level.

Table 7: Carbon Sequestration (Equivalent Tons)

Native species	At breast diameter avg (cm)	AGB (kg)	BGB (kg)	Total biomass	Carbon content	CO2 equi. (kg)	CO2 Equi. (tons)	The total number of trees (Appro.)	Total Co2 equi. (tons)
Neem	80	3606.1	540.9	4147.0	2073.5	7602.8	7.60	100	760.27
Axle wood	50	1278.4	191.8	1470.1	735.1	2695.2	2.70	50	134.76
Eucalyptus	120	8554.6	1283.2	9837.8	4918.9	18035.9	18.04	50	901.79
Babul	30	385.5	57.8	443.3	221.6	812.7	0.81	50	40.63
Bottle brush	4.5	11.5	1.7	13.2	6.6	24.3	0.02	50	1.21
Peepal	150	13649.7	2047.4	15697.1	7848.6	28778.0	28.78	50	1438.90
Banyan	200	24777.1	3716.6	28493.6	14246.8	52238.3	52.24	50	2611.91
Laurel fig	90	4645.5	696.8	5342.3	2671.2	9794.3	9.79	100	979.43
weeping fig	60	1922.5	288.4	2210.9	1105.4	4053.2	4.05	100	405.32
Indian Laburnum	60	1922.5	288.4	2210.9	1105.4	4053.2	4.05	100	405.32
Indian Mahogany	80	3606.1	540.9	4147.0	2073.5	7602.8	7.60	50	380.13
Bambusa vulgaris	10	19.7	3.0	22.6	11.3	41.5	0.04	50	2.07
Terminalia arjuna	150	13649.7	2047.4	15697.1	7848.6	28778.0	28.78	50	1438.90
Yellow Trumpet Tree	40	766.0	114.9	880.9	440.5	1615.0	1.62	50	80.75
Alstonia scholaris	90	4645.5	696.8	5342.3	2671.2	9794.3	9.79	100	979.43
Total		83440.1	12516.0	95956.2	47978.1	175919.6	175.92	1000	10560.87

Source: Referred and modified from Sharma, 2020.

The committee's report was presented to a Supreme Court bench led by Chief Justice of India S.A. Bobde, which had asked the committee to assess the monetary value of the trees in January 2020 based on the cost of oxygen released and other environmental advantages. Based on the report, a guideline on tree valuation for the first time in India was prepared, stating that a tree's monetary worth is its age multiplied by rupees 74,500.00 per tree year. This was presented to a Supreme Court bench. Out of this the cost of oxygen alone is rupees 45,000.00 and of biofertilizers, rupees 20,000.00.

Table 8: Carbon Sequestration Valuation

Trees year (age)	Monetary worth of one tree (INR)	No. of trees	Monetary worth (INR)
1	74500	1000	74500000
5	372500	100	37250000
10	745000	100	74500000
15	1117500	100	111750000
20	1490000	100	149000000=14.9cr

Source: Author

There would be 175 tons of carbon equivalent in a year sequestered if just one tree of each native species is planted (total 15 trees). Initially, trees will take an average time of 4-5 years in attaining maturity. To arrive at the monetary value, total native species were assumed that are to be planted initially. The assumed number of trees' monetary value with age was found out by multiplying it with 74,500 rupees per tree year.

Conclusion and Way Forward

The ecological riverfront prototype with ecosystem valuation is the first study of its kind in the Indian context undertaken in order to understand the role of rivers in the mitigation of urban heat islands (UHI) and climate change in the long term. So far, the studies done on UHI in the international context were focused on mitigation planning and monitoring whereas most of the studies in the Indian context were in the analysis stage, with mitigation guidelines being listed but attempts not yet made for implementation. In the international context, the studies have been done wherein the role of cool breezes from the rivers in urban areas have been observed through various experiment as helping in mitigation of UHI. A study by Akashi (2008) evaluates the effectiveness of reducing the UHI effect by creating 'wind corridors' in dense urban areas. This study describes how wind paths create chains of wind over the ocean, facilitating the ventilation of naturally heated air. The study by Kagiya & Ashie (2009) discusses the creation of ventilation paths along rivers or the seafront as a measure for mitigation of UHI. Another study by Hathway & Sharples (2012) identified the possible impact of small urban rivers in reducing the UHI effect and studied the role of urban morphology on the riverbank in the propagation or reduction of potential cooling. In the Indian context, the study by Veena, K M Parammasivam and T N Ventakesh (2020) sudden climatic changes and the rise of temperature in the urban area, that is the formation of Urban Heat Islands (UHI pointed out that more than 70 per cent of the research is related to the analysis of LST and surface temperature (ST) (that is, the study of surface heat islands), and about 30 per cent of the research is only in AHI (atmospheric heat island). Also, research work is limited to UHI testing and its findings but the implementation of mitigation efforts is missing. Other studies are by L. Vailshery, M. Jaganmohan, and H. Nagendra (2013) and Aslam M.Y., Krishna, K.R., Beig, G., Tinmaker, M.I.R. and Chate, D.M (2017) for UHI w.r.t air quality, R. Sharma & Joshi (2014) for LULCC and UHI, and The Energy and Resources Institute, (TERI, 2017) for urban planning and UHI. The study on The Economics of Ecosystems and Biodiversity (TEEB, 2010) demonstrates an ecosystem valuation technique that can be applied in different ecological contexts but it is still in the experimentation stage.

The present study of UHI in the context of Delhi to give a proposal for ecological riverfront development was unique as it involved not only identifying the UHI in a particular context but also the results obtained have given clarification concerning mitigation efforts needed to reduce ill effects of UHI or vice versa. The study focuses not only on the identification of the problem of UHI and various factors responsible for it but also on how to solve it through various mechanisms to be adopted and for its implementation at ground level. The design approach of the ecological riverfront addresses social, cultural, economic, environmental, aesthetical factors which will cater to the sustainable development of the model in the long term. The economic appraisal shows that the model in the initial two plus years only has the potential of creating a value up to approximately INR 60 crore which is very rare in investment model returns. The tangible and intangible benefits such as employment generated and improvement in air quality have not been calculated over here. If all this is added up its value will further increase. Further, the valuation of ecosystem services will create awareness among the people and will motivate them to promote and adapt to such development models in future. If such a development prototype is further implemented on a large scale, the tangible and intangible benefits to people would be ten times more than estimated. Such modelling in future will help in debating the issue of development versus environment by balancing development objectives particularly in the context of achieving SDG goals 2030.

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Conflict of Interest

Authors have no conflict of interest to declare.

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