

Urban expansion and wetland shrinkage estimation using QGIS- tool: A Kolkata Case-Study

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Abstract:

Urban wetlands are important natural reservoirs that help to regulate water cycles, weather and the environment at large in rapidly growing cities. Unfortunately, the fast pace of urban growth has led to the loss of many of these natural habitats. The paper explores spatial and temporal changes in the wetland areas of Kolkata through a GIS-NDWI method combined with forecast analysis. Different year satellite images were used in QGIS software to track water bodies in four different types of urban areas of Burrabazar (Urban Core), Salt Lake (planned city), Newtown (expansion zone), and the overall metropolitan area of Kolkata. The findings show that all the spatial levels there has been a slowly and continuously decrease in wetland areas. Overall, in the city, the water bodies have decreased from 2854.01km² or 7.82% in the year 2014 to 1834.02km² or 5.03% in 2023. A close-up focus shows that the water bodies in the urban core have practically disappeared, the planned urban areas (Saltlake) show a moderate level of water bodies 1.74% compared to urban core (Burrabazar) 0.98%, the expansion areas (Newtown) are beings wiftly deprived of water bodies 1.93%. The projected data shows with that the current pace of urbanization, the remaining water bodies will become separated and would fail to function hydrologically. Findings indicate a severe imbalance between the growth urban areas and ecological sustainability, and point out that wetland-sensitive urban planning, continuously geospatial monitoring and policy-oriented conservation strategies are very necessary to prevent permanent environmental loss. The research was verified by linear regression and polynomial regression (degree = 2) which estimated that in 2030 only 3.25% of wetland will be left in Kolkata and by 2040 it would have reached a saturation level.

Keywords: Urban wetlands, NDWI, GIS, QGIS, Spatio-temporal analysis, Urban expansion, Wetland Degradation, Kolkata

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1. Introduction

Wetlands are one of the most productive ecosystems on Earth. They help in many ways like storing carbon, treating wastewater, preventing floods and even changing the weather. But unfortunately, rapid urbanization in this anthropocene era is turning these very important blue green areas into grey impermeable surfaces more and more. This is particularly the case with fast-growing cities where the need for housing and industries is so great that environment is not given by other concerns. Besides biodiversity loss, the disappearance of urban wetlands leads to making the city more vulnerable to climate-induced disasters. This calls for better geospatial monitoring systems.

Globally, downtown wetland damage and disappearance have been well recorded and noticed. Studies done in the Netherlands indicate that urban-wetland disputes may become so severe that they might cause collapse by 2035 (Tendurus et al. 2013), and in addition, a wetland disappearance in the Chinese Zhujiang Delta led to the rise of land surface temperature the same way (Weng, 2001). In India regularly people have been reporting wetland disappearance in big urban agglomerations. For example, measuring the growth of developed lands at the expense of forest and water bodies in the last two decades in the Delhi NCR shows that it is 5.22% and Chennai, displacements of wetlands along the coastal areas vary from 23.14% to 15.79% with the coming of industrialization (Jacinta et al. 2019). At Kolkata, one of the highly vulnerable spots where the East Kolkata Wetland (EKW) zone is located, about 60% of its geographical area is encountering land encroachment mostly due to real estate and illegal land filling (Ghosh & Das, 2018; Chakraborty & Chatterjee, 2025).

Almost all the research work so far has been done on the protected wetland areas like the EKW Ramsar sites. However, a very few have engaged with the idea of comparing the loss of wetlands at the city-level of Kolkata not just of the ecologically wetted old city areas but also the present-day rapidly increasing peripheral regions. This paper seeks to address these gaps by looking at the old city areas' potential to the degrading ecological condition to act as an early warning system that can foresee the wetlands' collapse in the growth corridors in the future. NDWI analysis through QGIS has been the basis of the research in measuring the fragmentation trends of the entire Kolkata as well as the case study areas of Bara Bazaar, Salt Lake, and New Town. Finally, the research has employed machine learning techniques to forecast the trends of wetland change for the years 2030 and 2040 which will serve as a basis for scientifically-grounded suggestions for urban sustainability planning design based on resilience principles.

2. Literature Review

Various research has extensively shown the application of remote sensing and GIS in understanding urbanization and wetland transformation across different spatial framework. Weng (2001) showed how rapid urbanization in China led to notable environmental changes, highlighting the usefulness of satellite-based analysis for monitoring urbanization. Many studies showed more advanced modelling approaches, such as cellular automata (CA) and machine learning, to predict future urbanization and its ecological consequences. For example, studies in Europe and China integrated CA with random forest model to study urbanization and farmland or wetland loss, revealing strong linkages between infrastructure development and landscape splitting (Yao et al., 2017; Tendurus et al., 2013). Prolonged changes in wetland analysis showed how sustained man-made caused pressure alter the ecosystem

balance, shown in multi-decadal wetland studies (Li et al., 2015; Li, 2014). Systematic reviews of global LULC dynamics further integrated the understanding that population growth, policy shifts, and economic drivers are forces behind wetland degradation worldwide.

In the Indian context, studies have been focused on urban wetland ecosystems, particularly in rapidly urbanizing regions. Several studies from cities such as Coimbatore, Chennai, Delhi NCR, and Kanchipuram have applied geospatial techniques to quantify LULC changes and monitor their environmental impacts (Babykalpana & ThanushKodi, 2010; Jacintha et al., 2019; Yogesh Palanivel & Sanchikantananda, 2018; Singh et al., 2025). The East Kolkata Wetlands (EKW) have received special attention due to their ecological and socio-economic

significance, with multiple studies documenting wetland shrinkage driven by urban expansion between 1972 and recent years (Li et al., 2015; Mondal et al., 2017). Advanced decision-making tools such as fuzzy MCDM have been used to assess vulnerability and risk in EKW, highlighting increasing exposure to urban-induced stressors (Ghosh & Das; Banerjee & Dey). Other national-level studies linked wetland loss to microclimatic changes and declining ecosystem services, reinforcing concern over sustainability (Sannigrahi et al., 2019; Chakraborty et al., 2025; Rahaman et al.). Collectively, these studies underline the urgent need for integrated geospatial planning and policy interventions to safeguard India's urban wetlands.

3. Methodology

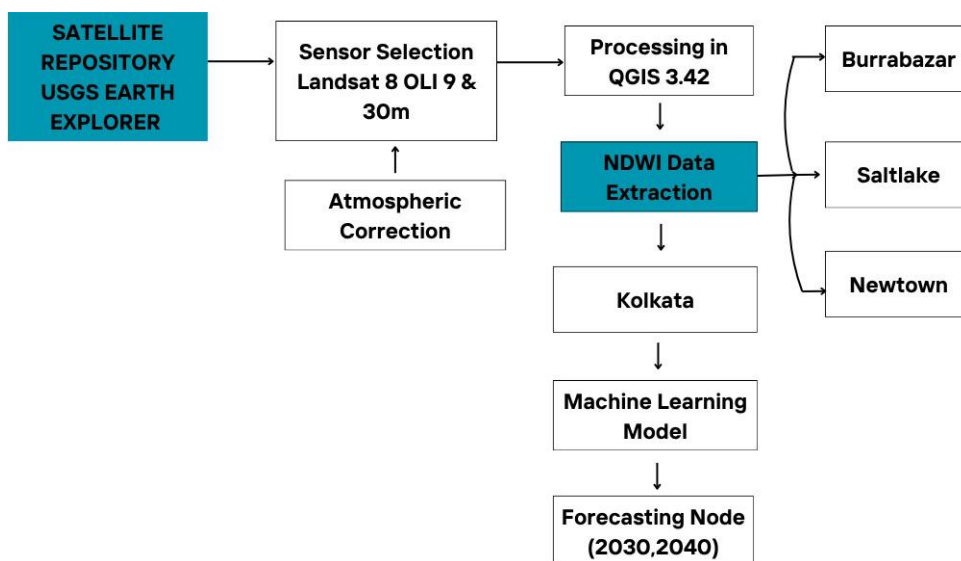


Fig1: Methodology Flowchart

3.1 Site Analysis: This site analysis includes the study of 3 places namely-Burrabazar, Salt Lake and Newtown metropolitan cities of Kolkata, West Bengal, India.

3.1.1 Burrabazar: Burrabazar was selected as a representative of the Urban Core, developed in the year 1738 which is characterised by high-density built-up infrastructure and a historical lack of planned open spaces.

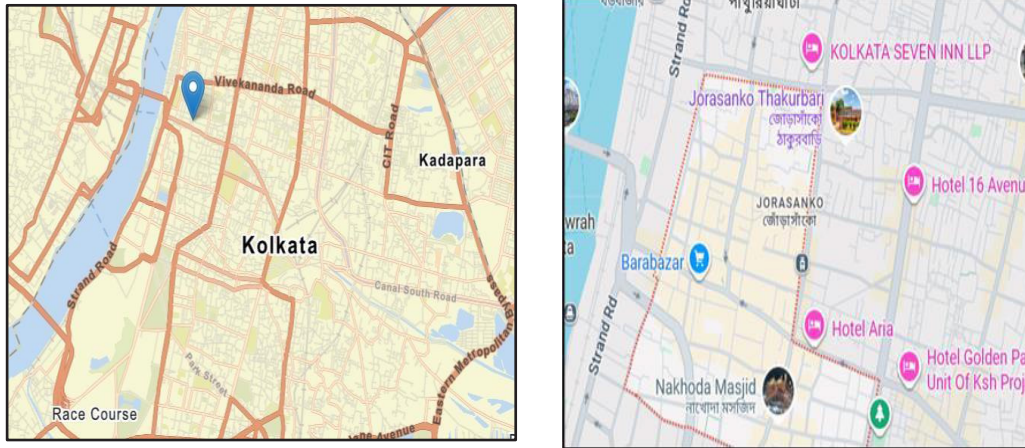


Fig2: Site Analysis of Burrabazar (a) Image from USGS Earth Explorer (b) Image from Google Map

3.1.2 Salt Lake (Bidhannagar): Salt Lake being a planned and developed in the year 1962 serves as a critical study area for understanding the transition from a wetland-dominant landscape to a planned urban environment.

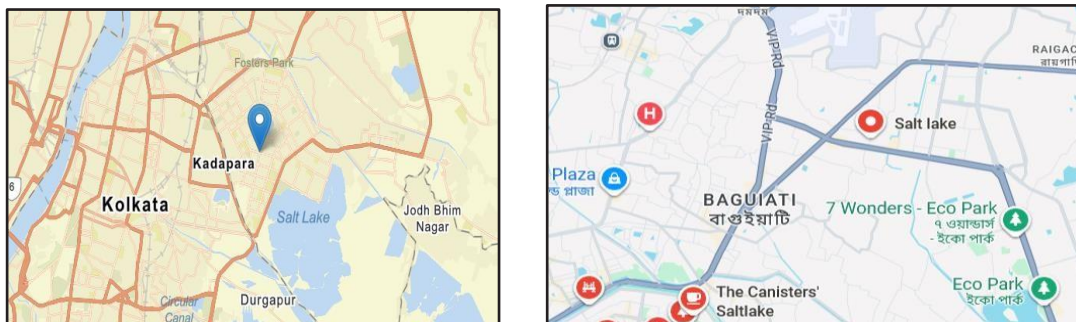


Fig3: Site Analysis of Salt Lake (Bidhannagar) (a) Image from USGS Earth Explorer (b) Image from Google Map

3.1.3. Newtown (ActiveExpansion): Newtown, Rajarhat represents the pre-urban expansion zone built in the year 1999.



Fig4: Site Analysis of Newtown (a) Image from USGS Earth Explorer (b) Image from Google Map

3.2 NDWI-Based Wetland Mapping and Spatial Analysis Using QGIS:

Multi-temporal satellite imagery from the Landsat series was utilised to assess urban wetland dynamics across Kolkata for the years 2014, 2017, 2020 and 2023. All satellite datasets were acquired from the United States Geological Survey (USGS) Earth Explorer platform and processed using QGIS with version 3.42, and open-sourced geographic information system. The images were first subjected to radiometric and atmospheric consistency checks, followed by spatial sub-setting to the defined study boundary of Kolkata, including the sub-regions of Burrabazar, Salt Lake and Newtown. To ensure spatial accuracy in area computation, all the layers were projected to a common projected coordinate reference system.

The normalised difference water index (NDWI) was employed to delineate surface water and wetland features, as they are effectively enhanced water bodies by contrasting reflectance in the green and near-infrared spectral bands. NDWI was calculated in QGIS using the raster calculator based on Landsat green and near-infrared bands. A threshold-based classification was applied to convert the continuous NDWI output into a binary water mask, where pixels with positive NDWI values were classified as water and negative values as non-water surfaces. This binary raster was subsequently converted into vector polygons using the raster-to-vector conversion tool to enable spatial and statistical analysis.

Non-water features were removed by selecting and retaining only polygons corresponding to water-class pixels. Polygon-level wetland area was calculated using the field calculator, generating area attributes expressed in square kilometres. Descriptive statistical parameters including feature count, minimum area, maximum patch size, mean area and total detected water area were computed using the basic statistics tool withing QGIS. These statistics were generated for the entire Kolkata Metropolitan Area as well as for the individual sub-regions of Burrabazar, Salt Lake and Newtown to capture spatial variability in urbanisation impacts. Wetland representation was performed through polygon-based classification, where each polygon was assigned a binary attribute DN, where DN=1 representing wetland areas and

DN=0 representing non-wetland areas. The corresponding polygon areas were computed in square kilometres (km²) and exported year-wise CSV files for further analysis.

The basis for wetland shrinkage and spatial changes over time came from the wetland statistics data which is collected for several years. To predict the future wetland conditions for 2030 and 2040 amid rapid urbanization, the final dataset was exported in excel format and then machine learning was used. This geospatial workflow provided reliable inputs for climate changes and urbanization in the field of sustainability research. It also allowed for systematic monitoring of wetland changes due to urbanization and other causes.

3.3 Machine Learning-Based Regression Modelling:

To predict how wetland areas might change in the future, used two machine learning techniques: linear and polynomial regression.

3.3.1 Linear Regression Model: Used Linear Regression as our baseline model to check for a straightforward, direct relationship between time (the year) and the percentage of wetland cover. This model assumes that the wetland area changes at a steady, constant rate over time. It is expressed by the standard equation:

$$Y = mx + c \tag{1}$$

, where y represents wetland percentage and x denotes the year.

3.3.2 Polynomial Regression Model (Degree = 2): Because the changes in wetland area did not follow a perfectly straight line, we also applied a second-degree polynomial regression model. This approach helps us capture the curve in the data, revealing whether the rate of the wetland loss is speeding up or slowing down over time. By transforming the input into higher-order terms, the model fits a curved relationship expressed as:

$$y = ax^2 + bx + c \tag{2}$$

, where y represents wetland percentage and x denotes the year.

A polynomial degree of two was selected to balance model flexibility and avoid overfitting, particularly considering the limited number of temporal observations.

4. Result:

4.1 WetlandAreaEstimation:

The total area of specific location is calculated by adding the polygon of those particular locations for each research years.

The total wetland area (DN = 1) is calculated from the QGIS simulation formulae as mentioned below:

Total Wetland area (DN=1) = (Wetland Area / Total Area) × 100

Percentage = (Wetland Area / Total Area) × 100

This procedure resulted in a dataset containing of Location, Year, Total Area, and Wetlands Area which was then used for modelling and prediction.

Table 1: Wetland Area Estimation of specific locations

SLNo.	Location	Year	Total Area km ²	Wetland Area km ²
1	Burrabazar	2014	36,496.74	780.39
2	Salt Lake	2014	36,615.04	839.70
3	Newtown	2014	34,816.24	1,244.41
4	Kolkata	2014	36,984.72	2,854.01

4.2. Wetland Estimation

4.2.1 NDWI-Based Surface Water Dynamics in Burrabazar:

The statistics relating to wetlands in Burrabazar based on NDWI analysis show that the trend of wetland deterioration in the Kolkata urban core on Table 2. In 2014, the wetland area in Burrabazar was 780.39 km² which represented 2.14% of the entire study area (36,496.74 km²). Despite the total number of polygons being quite high (15,352), the abundance of very small patch sizes (the value of main patch = 0.001 km) indicated the advanced fragmentation and absence of large, ecologically functional wetlands. In 2017, although there was a sharp rise the wetland area increased only to 812.15 km² (2.23%). This is an indication improved spectral detection of surface moisture, probably caused by the effect of monsoon flooding or the temporary water accumulation in the dense built-up parts rather than areal wetland recovery. The very large maximum patch size (93.34 km) at that time strongly corroborates the idea of hydrological events of short duration rather than the continual presence of a wetland. By 2020, the area of wetlands had shrunk once more to 687.93 km² (1.88%), meanwhile the largest patch size had fallen to 9.11 km. This is a sign that it is now the leading water bodies that have been broken down into very small patches. The consistent occurrence of the very small minimal area values (0.001 km) is a clear sign of water in Burrabazar shifting to very temporary features like drainage channels, rooftop storage and short-lived surface water-logging. The most dramatic change was in 2023 when the area of wetlands dropped to 357.05 km² which was only 0.98% of the total area. DN based classification shows that wetland pixels (DN = 1) are very broken and scattered. This time is almost equivalent to no wetlands in the city centre with almost all the few ones left being man-made or rainfall-dependent water bodies rather than natural wetlands. All in all, the situation of the Burrabazar area is an illustration of the almost irreversible of the almost irreversible urban wetland loss with extreme fragmentation, decrease in wetland percentage, and the disappearance of long-term hydrological storage capacity, which could be taken as a warning model for newly urbanizing areas.

Table 2. NDWI-derived surface water statistics for Burrabazar

Year	Total Area (km ²)	Wetland Area (km ²)	Wetland Percentage (%)
2014	36,496.74	780.39	2.14
2017	36,496.74	812.15	2.23
2020	36,496.74	687.93	1.88
2023	36,496.74	357.05	0.98

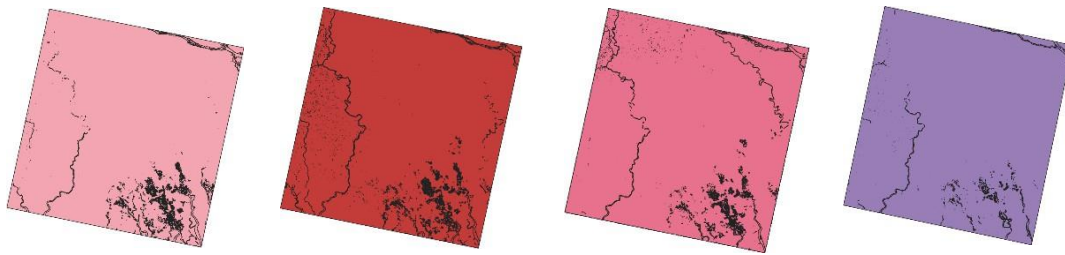


Fig 5: Polygonise Water index Map of Burrabazar of respective years –i)2013, ii)2017, iii)2020, iv)2023

4.2.2 Surface Water Evolution in Salt Lake (Bidhannagar):

The results of the NDWI-based wetland assessment for Salt Lake (Bidhannagar) show that the wetland conditions of this planned urban area built on the reclaimed wetlands are deteriorating moderately but steadily Table 3. In 2014, Salt Lake had a wetland area of 839.70 km², which was only 2.29% of the total area of the study (36,615.04 km²). Even under the sustained urban pressure, the planned canals, lakes, green buffers helped maintain some surface water. In 2017, the wetland extent of the city slightly increased, with the wetland area rising to 812.16 km² (2.22%). This slight gain does not seem to be a real wetland restoration, but rather local surface water retention within artificial reservoirs, parks and canals, that has been quite prominent during the monsoon period. Wetland coverage dropped to 786.39 km² in 2020 and the wetland percentage fell to 2.15%. This loss is indicative of the gradual filling and encroachments on moisture-bearing surfaces as the city densification increased. Although Salt Lake has a well-structured drainage system, conversion of open and semi-permeable areas into built-up land has been increasingly limiting the functionality of wetlands. In 2023, the wetland area has been reduced again to 638.66 km², which is only 1.74% of the total area (36,615.04 km²). This drop means changing from a semi-resilient hydrological system to a highly stressed urban wetland regime. Even though major water bodies are still there, they are losing their ecological effectiveness as they become increasingly fragmented and isolated from natural wetland networks. In general, Salt Lake is an example of an urban wetland degradation at a middle level, where the constructed infrastructure has only postponed the eventual reduction of wetland area as a result of continuous urban growth but has not stopped it.

Table 3. NDWI-derived surface water statistics for Salt Lake (Bidhannagar)

Year	Total Area (km ²)	Wetland Area (km ²)	Wetland Percentage (%)
2014	36615.04	839.70	2.29
2017	36615.04	812.16	2.22
2020	36615.04	786.39	2.15
2023	36,615.04	638.66	1.74

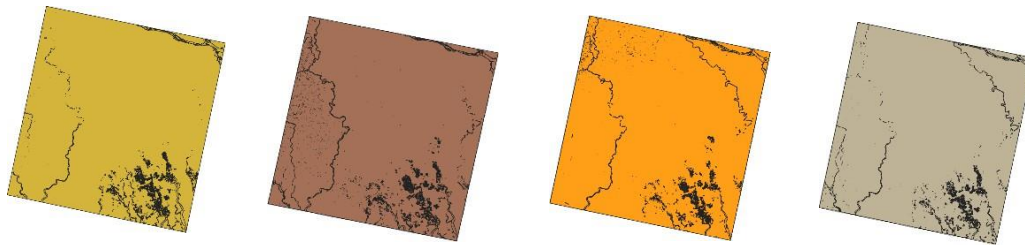


Fig6: Polygonised Water Index Map of Salt Lake (Bidhannagar) of respective years – i) 2013, ii) 2017, iii) 2020, iv) 2023

4.2.3 Wetland transformation along the Newtown:

ANDWI-based analysis of Newtown reveals that the area is a peri-urban expansion zone undergoing rapid infrastructure development and at the same time intersecting with existing wetland systems (Table 4). In 2014, Newtown had a relatively large wetland of 1,244.41 km² which was 3.57% of the total area (34,816.24 km²). This situation reflected the existence of large contiguous wetlands before the major urban consolidation, which was closely associated with the influence of the East Kolkata Wetlands. By 2017, the wetland area had substantially fallen to 1031.15 km² (2.96%), pointing to faster land reclamation and conversions as a result of residential, commercial and IT infrastructure developments. During this time, wetlands of large sizes were broken down into smaller, unconnected patches due to fragmentation. The decrease continued in 2020 as the wetland area went down to 798.39 km² (2.29%). Such a decline is in line with ongoing building works and the laying down of roadways, etc. all of which have led to a breakage of the natural water system connections. Wetlands at this time are more reflective of scattered pieces rather than full ecosystems. By 2023, Newtown went beyond the limit, the area of wetlands decreasing to 673.50 km², making up only 1.93% of the total area. This phase marks progression of wetland disappearance, as at this point any water features are essentially limited to man-made retention ponds, drainage canals or depressions holding water after rains. The fast decrease in Newtown is almost a replay of the very first steps in the path to the kind of situation one finds nowadays in the city-centre. In fact, Newtown is a good representative of a changing but at the same time fast going downhill wetland systems, which is a very strong call for action before going completely urban and finally wiping out the wetlands.

Table 4: Cumulative NDWI-based surface water statistics for Newtown

Year	Total Area (km ²)	Wetland Area (km ²)	Wetland Percentage (%)
2014	34816.24	1,244.41	3.57
2017	34816.24	1031.15	2.96
2020	34816.24	798.39	2.29
2023	34816.24	673.50	1.93

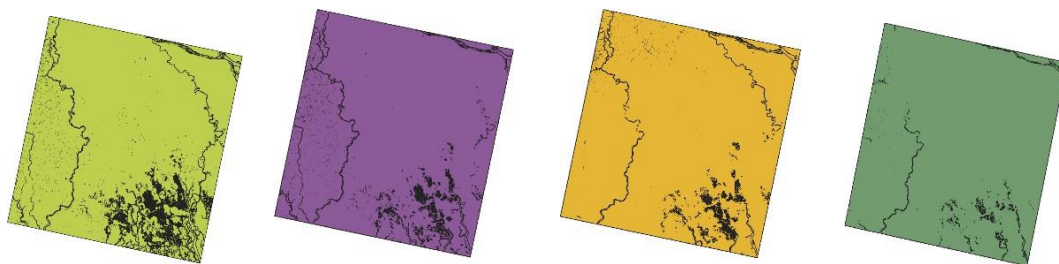


Fig 7: Polygonised Water Index Map of Newtown of respective years – i) 2013, ii) 2017, iii) 2020, iv) 2023

4.2.4 Macro Scale Wetland Dynamics of Kolkata:

The NDWI-based wetland assessment at the metropolitan scale reveals a progressive decline in wetland extent across Kolkata, despite the near-constancy of the total geographical area (Table 5). In 2014, Kolkata recorded a substantial wetland area of 2,854.01 km², accounting for 7.82% of the total area (36,984.72 km²). This period represents a relatively stable baseline condition, where large wetland systems – primarily linked to the East Kolkata Wetlands – still maintained spatial continuity. By 2017, wetland area declined sharply to 2,357.03 km² (6.46%), indicating rapid urbanization during this phase. The extent of wetland loss indicated that it was not limited to small-scale fragmentation but involved the division of larger wetland bodies into small units. By 2020, wetland area dropped to 2,311.54 km², or 6.25% of the total area. This time period showed that with excessive violation and urbanization led to loss of wetland in metropolitan area. The situation worsened in 2023, when wetland area sharply decreased to 1,834.02 km², only 5.03% remaining. This shift moved from healthy wetland to significant wetland loss at the city level leading to disbalance of ecosystem. Most of the remaining wetlands are now small fragmented parts of large water bodies or artificial wetlands depending on rainfall.

Table 5. Cumulative NDWI-based surface water statistics for Kolkata

Year	Total Area (km ²)	Wetland Area (km ²)	Wetland Percentage (%)
2014	36984.72	2854.01	7.82
2017	36984.72	2357.03	6.46
2020	36984.72	2311.54	6.25
2023	36984.72	1834.02	5.03

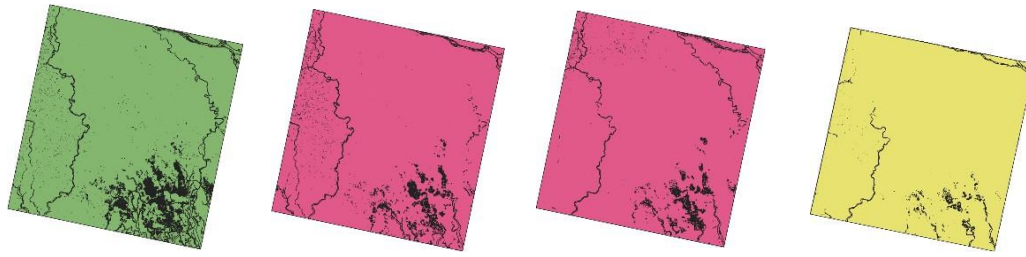


Fig8: Polygonise Water index Map of Kolkata of respective years – i) 2013, ii) 2017, iii) 2020, iv) 2023

4.3 Data Visualization and Trend Analysis:

The observed wetland percentages were plotted against time to monitor the fluctuation in wetland cover. A simple linear assumption would not actually represent the dynamics of wetland loss in Kolkata due to urbanization as it showed non-linear trends and annual fluctuations.

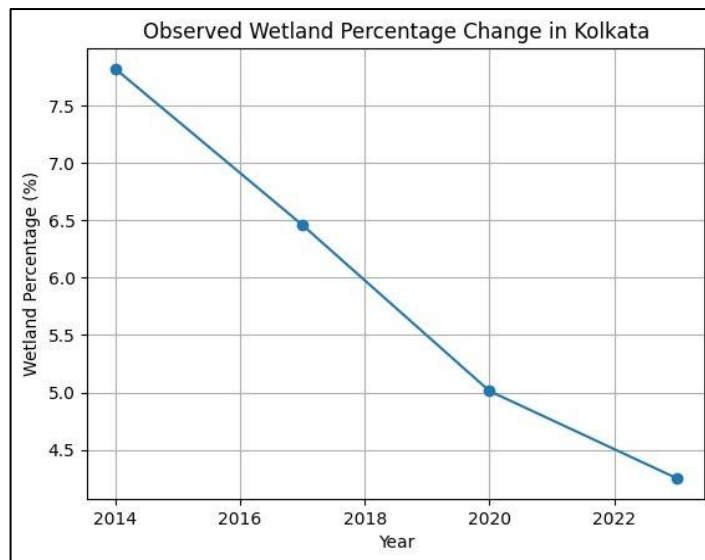


Fig9: Observed Wetland Percentage trend

4.3.1 Model Performance Evaluation:

The coefficient of determination (R^2) which tells us how much of the variation in wetland percentage is explained by the regression models. Higher R^2 values indicate a better fit between observed and predicted values.

Table 6: Comparative analysis of R² scores was used to identify the more suitable model for future projections.

ModelName	R ² Score
LinearRegression	0.98
PolynomialRegression	0.99

4.3.2 FutureWetlandCoverPrediction:

Usingthetrainedregressionmodels, wetlandpercentageswereprojected for theyears2030, 2035,and2040.Bothlinearandpolynomialmodeloutputsweregenerated;however,greater emphasiswasplacedonpolynomialregressionresultsduetoitsimprovedexplanatorypower.

Table7: PredictedWetlandpercentage

Sl.No.	Year	PredictedwetlandbyLinear Regression Model (%)	PredictedwetlandbyPolynomial Regression Model (%)
1	2030	1.22	3.25
2	2035	-0.79	3.56
3	2040	-2.8	4.71

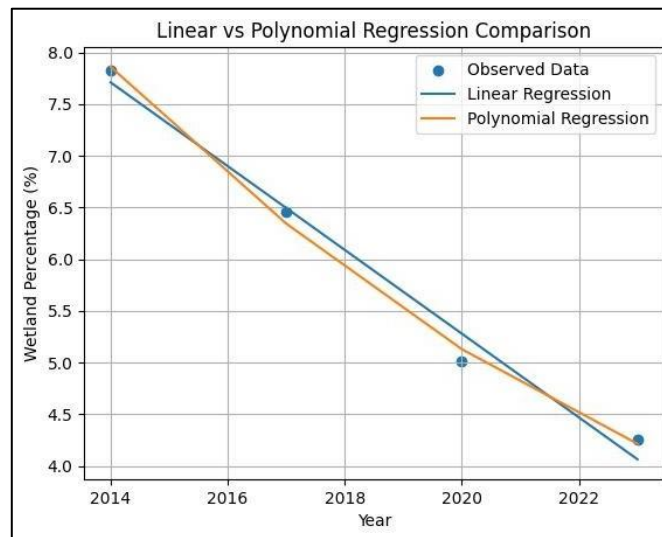


Fig10: LinearRegressionvsPolynomialRegression

Linear and polynomial regression techniques were used to study the change of wetland area in percentage over time in Kolkata. Although the linear regression model was very successful as reflected in the high value of the coefficient of determination ($R = 0.98$), it assumes the rate of change to be constant and thus fails to properly identify the complex non-linear changes of wetland resulting from different urbanization scenarios. Besides, the linear extrapolation even led to drastically negative values of wetland in percentage, which is impossible physically for long-term projections. On the other hand, the polynomial regression model of degree two with a better fit ($R=0.99$) not only matched the shape of the changes over time in the data very well but also gave projections which were more physically realistic. Therefore, polynomial regression was the final decision for future wetland percentage prediction the preferred model for future wetland percentage estimation

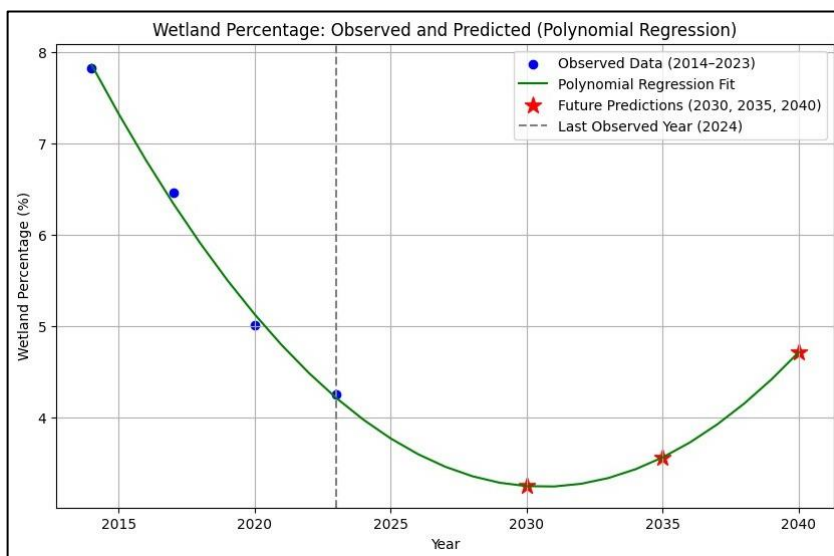


Fig 11: Predicted Wetland Loss

Negative values indicate a projected increase in wetland coverage, while positive values denote a decline relative to the baseline year.

4.4 Estimation of Wetland Loss: To determine the number of wetlands that would see disappearance, expected percentages of wetlands for upcoming years were compared with the actual value for 2023, which was used as the reference time. While the Polynomial model has a higher R^2 score (0.99) compared to the Linear model, it is highly sensitive to the curvature of recent data. In environmental science, this 'increase' might be interpreted as the potential result of aggressive conservation efforts post construction phase or restoration projects, though mathematically it is simply the extrapolation of a second-order curve.

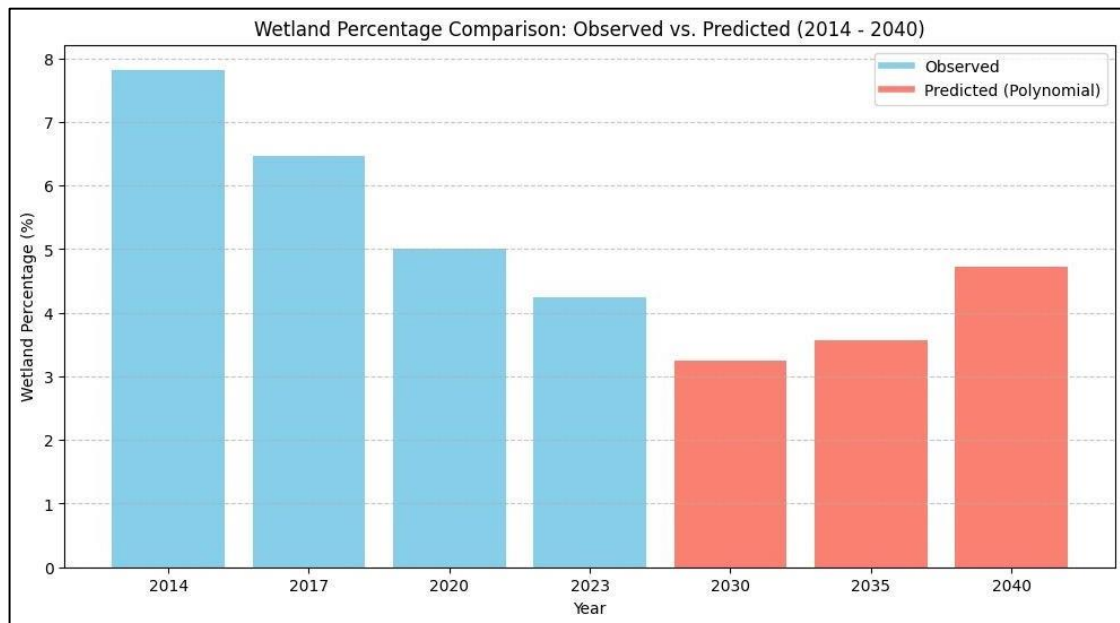


Fig12: Predicted Wetland Loss

5. Conclusion:

This research offers a detailed GIS-based examination of wetland changes in Kolkata that uncovers a significant and spatially uniform reduction in the wetland area in the period of 2014-2023. Although the boundary of the metropolitan area seems unchanged, the internal urban typologies. The decrease from 7.82% to 5.03% wetland cover at the city level is not just a reflection of the physical loss of wetlands but also of their fragmentation and the weakening of the functions of the remaining hydrological systems. On a fine scale, Burrabazar (0.98%) is shown to be at a very late stage of wetland extinction, extremely fragmented and dominated by tiny-scale, temporary water bodies. Salt Lake (1.74%) is at a stage of intermediate degradation in which the development of infrastructure planned has delayed but not completely stopped the loss of wetlands. New Town (1.93%) exemplifies this rapid transformation, highlighting how unchecked urban expansion quickly consumes wetland when regulatory and ecological safeguards are missing. Together, these areas illustrate distinct spatial patterns of wetland degradation, Kolkata's wetlands will not only continue to shrink but will also lose their vital ecological functions. This loss poses a severe risk of urban flood control, groundwater recharge, and overall climate resilience. Ultimately, our findings emphasize the urgent need to integrate geospatial monitoring tools with urban planning systems, alongside stricter conservation policies to protect the remaining wetlands. The GIS-NDWI method applied in this study offers a scalable and replicable tool for tracking habitat changes in any rapidly urbanizing region. Based on proposed regression models, it is predicted that by 2030, only 3.25% of wetland will remain in Kolkata, reaching a critical saturation point by 2040. In spite of regression models showing a strong fit, however, this research work acknowledges limitations due to limited temporal data aligned with three-year construction phase assumptions, but long-term forecasts carry inherent uncertainty.

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