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Freshwater Resources in Delhi: A Decadal Analysis of Land Use Changes

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Abstract

The escalating global concern over the pollution of freshwater resources, driven by the amplifying stress and scarcity of freshwater, underscores the significance of this study. The investigation examined the alterations in land use and land cover (LULC) in Delhi, concurrently assessing the coliform count in water sources designated for drinking and other purposes. LANDSAT 7 satellite imagery scrutinized the LULC changes in Delhi over a decade (2011 to 2021) to discern the impact of urban development. The outcomes of the LULC analysis reveal a noteworthy 2.03% expansion in built-up areas, while a reduction of 3.3% in forested regions and 0.43% in water bodies within the Delhi landscape. The amalgamation of mapping results with water quality data from the Central Pollution Control Board (CPCB) indicates a compromised supply of freshwater resources, particularly prevalent in South and Southwest Delhi. Additionally, biological data from the National Water Quality Monitoring Programme (NWMP) by the CPCB underscores that none of the sampled sites adhere to the drinking water standards prescribed by the CPCB. Notably, specific sites in South Delhi, namely Fateh Pur Beri, Pilanji, and Vasant Kunj, exhibit coliform counts surpassing 50 MPN/100 ml, which is unfit for bathing purposes as well. The comprehensive findings collectively illuminate the substantial footprint of urbanization in Delhi and its presumed impact on groundwater quality in the Delhi region. Furthermore, the study brings to light an ancient stepwell with sulfur-rich water that has sustained through urban sprawl and the continuous deterioration of water quality over the years.

Keywords: LULC, *E. coli*, water quality, groundwater, Delhi, GIS

INTRODUCTION

The scarcity of water resources and pollution, particularly in surface freshwater, has emerged as a significant concern owing to global economic growth and a growing population, presenting substantial public health risks [1, 2]. In India, 70% of the available 4% of freshwater is polluted, and major cities are facing a significant depletion of groundwater resources [3]. The disruption of the natural hydrograph primarily stems from human activities, notably the construction of dams, irrigation channels, river embankments, and water transfer channels to fulfill social and economic needs [4]. However, urbanization, industrialization, and irrigation systems contribute to increased salinity and deteriorating water quality [5, 6] by introducing substances such as nutrients (resulting in eutrophication) [7], heavy metals [8], antibiotics [9], nitrogen and sulfur compounds (leading to acidification) [10, 11], organic compounds [12], and pathogenic microorganisms (such as bacteria, protists, or amoebae) [13], which pose a threat to human life. Moreover, the decline in water quality poses a significant concern for inland water bodies that play a crucial role in the economy (through

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fisheries, livestock, and forestry), society (as sources of water supply), and environment (by contributing to groundwater recharge, nutrient recycling, and biodiversity maintenance) [14].

The introduction of remote sensing and Geographical Information System (GIS) techniques has provided a valuable and detailed method for mapping land use/cover and capturing the distribution of physical features of the land, including soil, water, and vegetation [15]. Satellite-assisted data capture allows us to observe changes in LULC over time, delivering observations regarding the temporal dynamics of the Earth's surface. Essentially, LULC change refer to quantitative changes in the area (either increase or decrease), which have been extensively studied [16, 17]. A recent study conducted by Yao et al. (2023) examined the degradation of water quality and its potential drivers, particularly urbanization, using LULC data. This study can inform future policy planning and development initiatives to achieve sustainability.

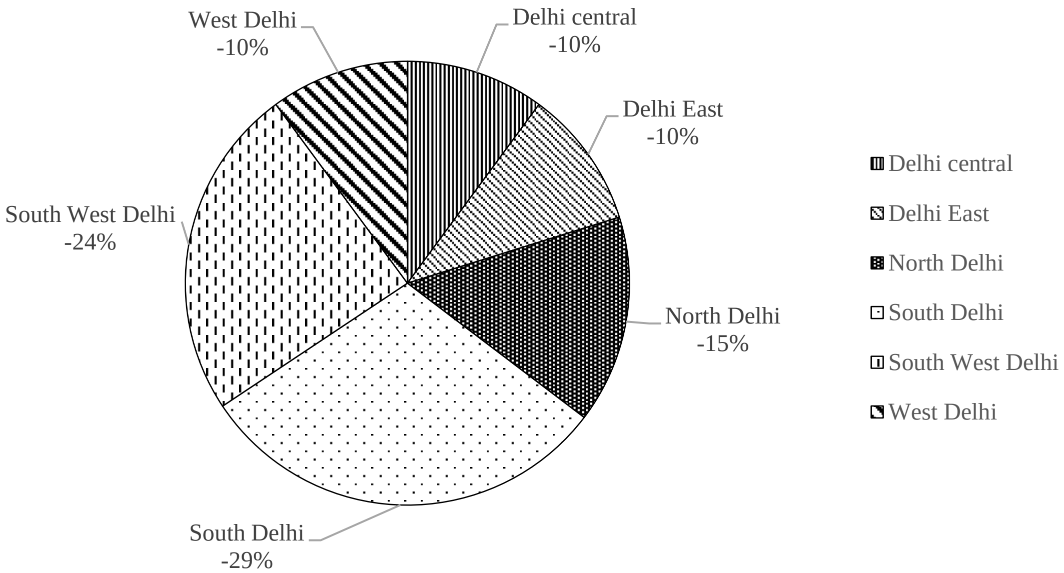

Figure 1. The chart displays the percentage distribution of over-exploited freshwater systems in Delhi. The South and South West districts exhibit the highest reported instances of over-exploited freshwater resources, with the North Delhi district following closely behind.

Delhi, the city facing the most water stress in India (Table 1 and Figure 1), has seen studies primarily focusing on changes in built-up areas, agricultural land, and vegetation cover. However, changes in freshwater quality and quantity have not been widely considered. For example, Jain et al. (2016) observed a 30.61% increase in built-up area, a 22.75% decline in cultivated area, and a 5.31% decrease in forest cover from 1977 to 2014 [18]. Naikoo et al. (2020) noted a 326% increase in built-up areas, a 12% decline in forest areas, and a 34% decrease in vegetation cover from 1990 to 2018 [19]. Singh et al. (2022) found a 13.44% expansion in built-up areas, a 10.88% decrease in cropland area, and a 3.48% increase in forest area from 1989 to 2020 [20]. Delhi's rapid economic development has led to expansion, potentially affecting water quality and quantity. Hence, this study focused on analyzing changes in land use, trends, and their impacts on freshwater resources within geographic boundaries.

MATERIAL AND METHOD

Study Area

Delhi is positioned within the northern region of the Indian subcontinent at a latitude of 28.61°N and longitude of 77.23°E (Figure 2). It shares its borders with the states of Uttar Pradesh and Haryana, covering an area of 1483 square kilometers. This choice of location enables a comparative study of urban expansion and its association with the quality of the inland water bodies in the region.

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Table 1. The status of the freshwater resources in different districts of Delhi.

District	Samling site	Categorization (Over-Exploited/Critical/Semi-Critical/Safe/Saline)
Delhi Central	Civil Lines	Safe
	Karol Bagh	Over-Exploited
	Kotwali	Semi-Critical
Delhi East	Gandhi Nagar	Semi-Critical
	Mayur Vihar	Critical
	Preet Vihar	Semi-Critical
	Seemapuri	Critical
	Shahdara	Over-Exploited
	Vivek Vihar	Over-Exploited
North Delhi	Alipur Tehsil	Semi-Critical
	Model Town	Critical
	Narela tehsil	Over-Exploited
	East Karawal Nagar	Over-Exploited
South Delhi	Hauz Khas	Over-Exploited
	Mehrauli	Over-Exploited
	Saket tehsil	Over-Exploited
	Chanakyapuri	Over-Exploited
South West Delhi	Delhi Cantonment	Over-Exploited
	Vasant Vihar	Over-Exploited
	Dwarka	Over-Exploited
	Kapashera	Over-Exploited
	Najafgarh	Semi-Critical
North East Delhi	Seelampur	Critical
	East Yamuna Nagar	Semi-Critical
North West Delhi	West Kanjhawala	Safe
	Rohini	Safe
	Saraswati Vihar	Semi-Critical
South East Delhi	Defence Colony	Critical
	Kalkaji	Critical
	Sarita Vihar	Critical
West Delhi	Patel Nagar	Critical
	Punjabi Bagh	Semi-Critical
	Rajouri Garden	Over-Exploited

Source: GWRA, 2022.

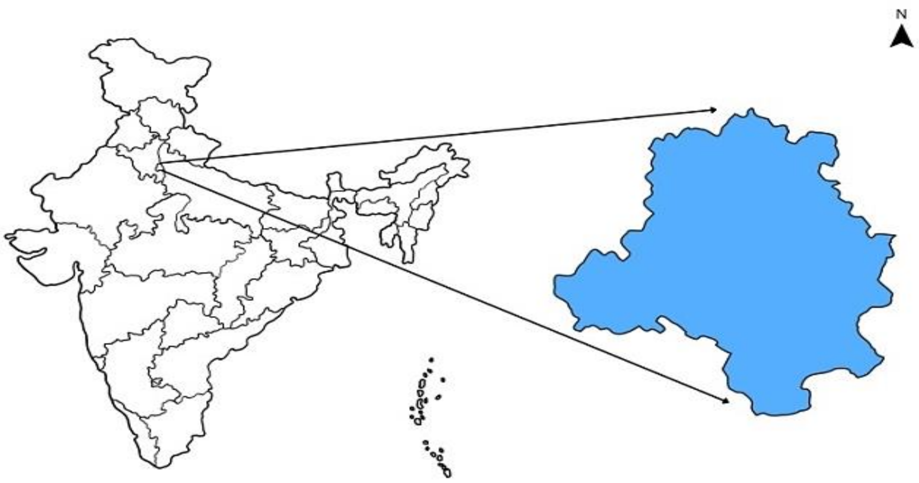

Figure 2. Study area, Delhi.

Data Collection
Software & Base Map
Obtaining and setting up a base map (India) is the first step in analyzing LULC. The base map used in this study was obtained from the Census of India Digital Data. For image processing, we employed QGIS software version 10.2.2. Thematic maps from satellite images were created using this software, which involved steps such as creating composites and unsupervised classification.

LULC Classification Data
The study used LANDSAT satellite images from the USGS Earth Explorer data portal (*https://earthexplorer.usgs.gov*) for 2011 and 2021 (Table 2). The 2011 images were obtained from the LANDSAT-7 ETM satellite, and the 2021 images were obtained from the LANDSAT-8 OLI/TIRS satellite. It's important to highlight that when selecting satellite images for Land Use Land Cover (LULC) analysis, care was taken to choose data with no cloud cover over land. This precaution is vital because clouds in the images can misrepresent the actual LULC on the ground.

The vector map layer, in conjunction with the satellite images, was merged to create false-color composites, and the dataset was clipped to focus our observation specifically on the LULC of Delhi.

Table 2. Data source.

Year	Type of LANDSAT satellite used	Date	Bands used	Resolution (in meters)
2011	LANDSAT-7 ETM	01 April 2011	2,3,4,5	30
2021	LANDSAT-8 OLI/TIRS	01 April 2021	2,3,4,5	30

Unsupervised Classification and Change Detection
Digital image classification is a method used to identify key features and categorize them into different groups, primarily to assess changes over space and time. In this process, pixels with a similar characteristics were grouped to form a category based on their spectral signatures. This categorization helps describe their spatial information and distinguishes them from pixels with different spectral characteristics that belong to another category. In this study, we focused on classifying built-up areas, forest cover, non-forest areas, and water bodies (including drains) through image classification. To simplify this process in QGIS, we utilized the integrated "Raster k-means clustering" tool for unsupervised classification (as illustrated in Figure 3). Additionally, we used a method called post-classification comparison to determine how the way we use and cover the land has changed over ten years.

Biological Indicator Data
To acquire data on biological indicators of groundwater quality for the year 2020, information was obtained from the Central Pollution Control Board (CPCB) under the National Water Quality Monitoring Programme (NWMP). The real-time data from the CPCB were subsequently correlated with LULC data to examine potential relationships or patterns.

RESULT AND DISCUSSION
LULC and Change Detection
The classified images depicting the four classes, that is built-up area, forest area, water bodies (along with drains), and other/non-forest areas for 2011 and 2021 are shown in Figure 4. The images reveal noticeable urban expansion in the northern and southwestern regions of Delhi, attributed to rapid population growth, immigration, and development along major transportation routes [21] and a substantial loss of agricultural land across the entire study area. Furthermore, without delving into specific figures, there is an observable reduction in water levels along the Yamuna River, which serves as a significant freshwater source for Delhi, over the years [22].

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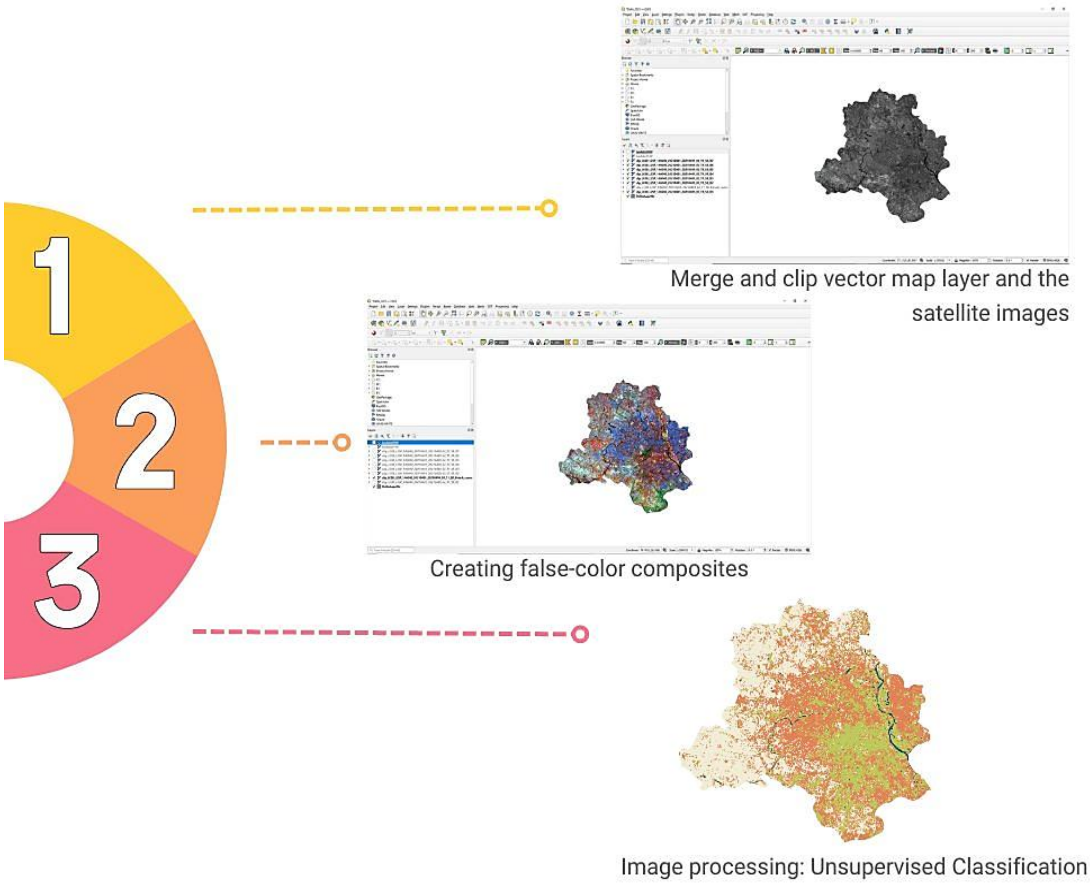
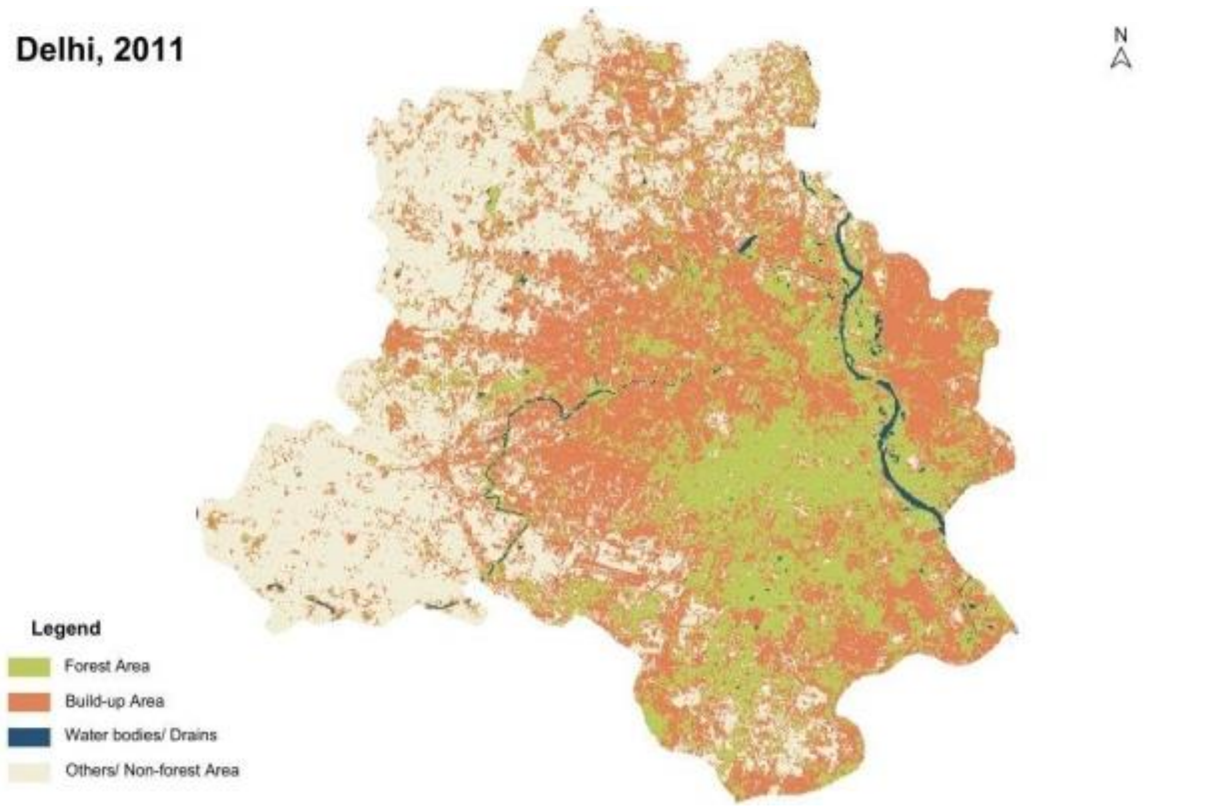


Figure 3. Steps involved in conducting unsupervised LULC classification of Delhi.



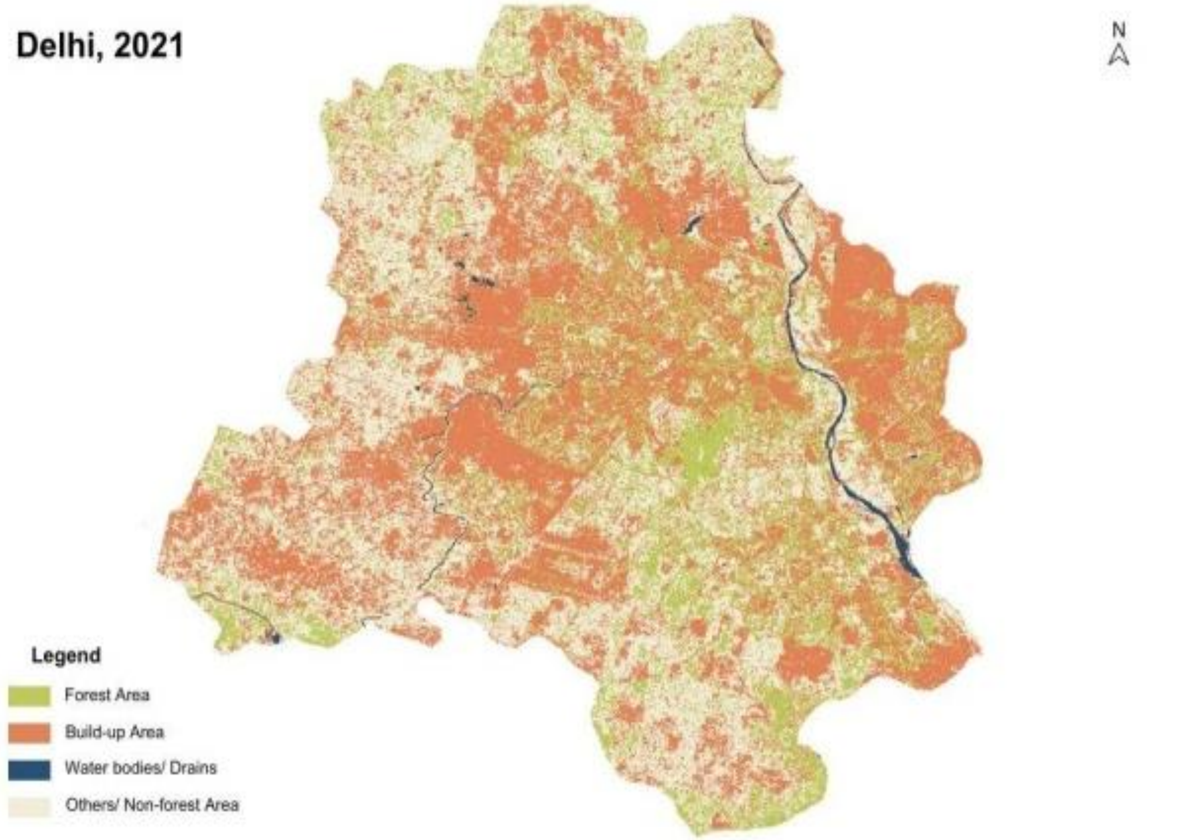


Figure 4. LULC of Delhi in the year 2011 and 2021

The extent and percentage of change in LULC from 2011 to 2021 are summarized in Table 3 and Figure 5. In 2011, the land use types were as follows: built-up area, 39.5%; forest area, 23.4%; water bodies, 1.25%; and other/non-forest land (including fallow land, agricultural fields, and open spaces) 35.9%. Over the ten years, built-up area and other/non-forest land increased by 2.02% and 1.7%, respectively. However, water bodies (including drains) decreased by 0.43%, and forest area decreased by 3.29%. In alignment with recent studies by Sing et al. (2023) and Tanwar et al. (2023), the built-up area has shown a sprawling trend, while the rate of change for water bodies is declining. On the other hand, the forest trend seems different because it includes both natural vegetation and forest cover, even though the true forest cover in Delhi was only about 23% (until 2011). Recent governmental efforts, such as plantation drives, city forests, and urban green spaces, have promoted the growth of natural vegetation [23].

Table 3. Pixel count and percentage distribution of different land classes (buildup, forest, water, and other regions) in Delhi for the years 2011 and 2021.

LULC	**2011**		**2021**		**Net change (%)**
	Pixel count	***Percentage (%)***	***Pixel count***	***Percentage (%)***	
Built-up	2635634	39.48	692126	41.5	2.02
Forest Area	1561699	23.39	335166	20.1	-3.29
Other/Non-Forest Land	2396670	35.9	626916	37.6	1.70
Water Bodies + Drains	83442	1.25	13653	0.82	-0.43
Total	6677445		1667861		

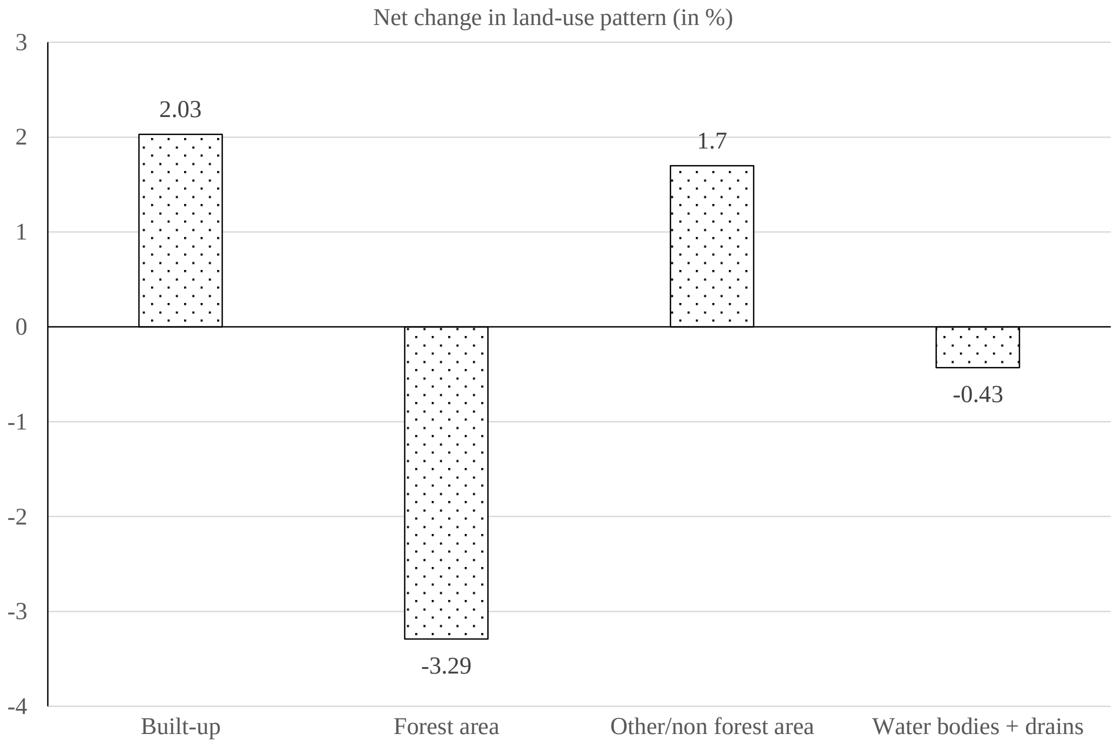


Figure 5. Percentage change in various land classes (buildup, forest, and other region) in Delhi over the course of a decade (2011–2021).

Groundwater and Biological Indicators

Groundwater and the Yamuna River are the primary sources of freshwater for Delhi residents. Expanding urban areas, as noted by Tanwar et al. (2023) has added pressure to groundwater resources. The decline in water quality is not solely attributed to urbanization; inadequate sanitation in unauthorized colonies near the Yamuna River [24] and industrial waste discharge [25] into freshwater resources also significantly contribute. Many studies have focused on measuring physicochemical factors, such as pH, total dissolved solids, nitrate, fluoride, salinity, and dissolved oxygen. In assessing water quality, biological indicators, such as fecal coliforms, total coliforms, and fecal *Streptococci* are often overlooked. However, their presence signals potential contamination from human or animal fecal matter, posing a risk of waterborne diseases [26]. *E. coli*, the prominent microbe in the coliform group, can rapidly mutate and develop resistance to antimicrobial agents, making it a highly adaptive microorganism of significance.

The CPCB regularly assesses biological indicators; the values for these indicators reported in 2020 are presented in Table 4. The highest bacterial counts were observed in Alipur, with 400 MPN/100 ml for fecal coliform and 5400 MPN/100 ml for total coliforms. Pilanji followed 170 MPN/100 ml fecal coliform, 1100 MPN/100 ml total coliform, and 230 MPN/100 ml fecal *Streptococci*. Vasant Kunj recorded 350 MPN/100 ml total coliform, Peeragarhi had 280 MPN/100 ml fecal *Streptococci*, Fateh Pur Beri showed 94 MPN/100 ml total coliform, and Patparganj Industrial Area had 74 MPN/100 ml total coliform. Among these, Alipur is in North Delhi, Pilanji, Vasant Kunj, Fateh Pur Beri are in South Delhi, and Patparganj is in the eastern zone of Delhi. This indicates that areas with unauthorized and unplanned urban sprawling (as observed in the LULC mapping) negatively impact groundwater quality. Despite substantial urbanization and the presence of data, Gandhak-ki-baoli, an ancient well in Mehrauli, South Delhi, has maintained its medicinal properties over the years. Hence, this 13th-century well stands as a unique and underexplored habitat for bacterial community diversity and bioactive compounds.

Table 4. pH and biological indicators (fecal coliform, total coliform, fecal Streptococci) at various sampling sites across different zones in Delhi (CPCB, 2020).

Sampling site	pH		Fecal Coliform (MPN/100 ml)		Total Coliform (MPN/100 ml)		Fecal *Streptococci* (MPN/100 ml)	
	Min	*Max*	*Min*	*Max*	*Min*	*Max*	*Min*	*Max*
Alipur	7.3	7.3	400	400	5400	5400	22	22
Aurbindo Marg	7.5	7.5	2	2	2	2	-	-
Bawana	7.7	7.7	2	2	2	2	2	2
Burari	7.5	7.5	2	2	4	4	2	2
Defence Colony	6.8	6.8	2	2	8	8	-	-
Dilshad Garden	7.2	7.2	2	2	2	2	2	2
Dwarka	7.3	7.3	4	4	27	27	17	17
Fateh Pur Beri	7.1	7.1	4	4	94	94	-	-
Gajipur	7	7	4	4	13	13	-	-
Gandhi Nagar	7	7	2	2	14	14	-	-
Haiderpur	8.2	8.2	2	2	2	2	2	2
ISBT	7.6	7.6	2	2	8	8	33	33
Kalka Ji	7.3	7.3	2	2	2	2	-	-
Kamla Nagar	7.6	7.6	2	2	2	2	2	2
Karol Bagh	7.7	7.7	2	2	13	13	2	2
Matiala	7.3	7.3	2	2	2	2	11	11
Maya Puri	7.4	7.4	2	2	5	5	4	4
Mayur Vihar	7.5	7.5	2	2	2	2	-	-
Najafgarh	7.1	7.1	2	2	7	7	2	2
Naraina Industrial Area	7.2	7.2	2	2	2	2	-	-
Okhla	7	7	2	2	33	33	-	-
Parivesh Bhawan	7.2	7.2	2	2	2	2	2	2
Paschim Vihar	7.8	7.8	2	2	2	2	2	2
Patel Nagar	7.3	7.3	2	2	11	11	2	2
Patparganj	7.2	7.2	2	2	4	4	-	-
Patparganj Industrial Area	7.7	7.7	22	22	79	79	-	-
Peeragarhi	7.2	7.2	2	2	2	2	280	280
Pilanji	7.5	7.5	170	170	1100	1100	230	230
Priya Enclave	7.1	7.1	2	2	2	2	2	2
Qutab Garh	7.7	7.7	2	2	2	2	2	2
Rajender Nagar	7.2	7.2	2	2	17	17	2	2
Rajpura Road	7.3	7.3	2	2	4	4	2	2
Gurudwara Shri Rakabganj Sahib	7.1	7.1	2	2	8	8	-	-
Rohini	8.1	8.1	2	2	2	2	2	2
Saket	7.1	7.1	2	2	2	2	-	-
Shahdara	7.1	7.1	2	2	2	2	2	2
Singhu Border	7.5	7.5	2	2	4	4	5	5
Singola	7.6	7.6	2	2	5	5	2	2
Sultanpuri	7.8	7.8	2	2	27	27	5	5
Tikri Kalan	7.9	7.9	2	2	2	2	2	2
Tilak Nagar	7.2	7.2	2	2			2	2
Trilokpuri	7.7	7.7	2	2	2	2	-	-
Ujwah	7.6	7.6	2	2	2	2	-	-
Vasant Kunj	7	7	2	45	8	350	-	-
Vasant Vihar	7.2	7.2	2	2	2	2	-	-

CONCLUSION

Over the course of evolution, change is inevitable because of the change in climate or the pattern of LULC. This study aims to examine changes in LULC, focusing on water body land use in Delhi, to raise awareness about the need to protect freshwater resources. The findings show various land use changes from 2011 to 2021, indicating their impact on groundwater quality and quantity. Tanwar et al. (2023) found shallow groundwater depths in the northern and northeastern areas and deeper depths in the central, southwestern, and southern parts due to land use changes. However, the present study highlights the water quality degradation in these areas (north, northeast, and southwestern regions of Delhi) due to increased and unplanned residential development. Furthermore, there is a risk of deterioration in water quality and quantity in the central region, where forested areas are fragmented into built-up or fallow lands. *Escherichia coli*, a highly adaptive microorganism, has gained scientific interest owing to its rapid mutation and resistance to antimicrobials. Moreover, this study has the potential to enhance planning for surface water resources and land development. However, for sustainable solutions, additional analysis is required because of insufficient data. This study will aid the Delhi Government's initiatives to restore freshwater bodies by recommending regulations for land use in the adjacent areas.

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