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Analysis of Land Use Change Effects/Impacts on Surface Water Resources in Delhi

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Abstract: Rapid urbanization and haphazard development derive the changes in land uses and affect the naturally available resources which are essential for human development and other lives. Land use changes can undermine the environment and ecology of an urban area. Although many studies on the land use changes, trends, status, directions, and the relationship between them have been conducted for Chinese cities, none of them have been completed for Indian cities and also not for NCT Delhi. The aim of the study is to analyze the impact of land use changes on surface water resources. So, this study aims to analyze the effects of land use changes on surface water resources in NCT Delhi, one water-stressed city in India. The analysis is comprised of changes, trends, status, and directions for surface water resources and other types of land use for showing the effects. Comprehensive tools such as remote sensing, GIS, and the cross-tabulation method are used for the assessment of land use changes, trends, and status. Four decadal (1990, 2000, 2010, 2020) satellite maps have been used to study the temporal-spatial data of several land uses and to calculate the index of land use changes for investigating the trends and status. In the form of results, the comprehensive net change (18.28%) and total change (49.28%) with a trend value of 0.37 show the quasi-balanced, two-way transition and positive changes in the whole area. This metrics-based study shows that surface water resources land use type is decreasing, and built-up land use type is increasing since 1990. Population growth, economic and industrial development were the major factors for the variations in built-up, green, and other land uses. This metrics-based analysis study is an important perspective for protecting urban water bodies from effects of land use changes. These understandings on land use changes and temporal-spatial relationships are important for present and future land use development and surface water resource planning. This study will help the Delhi Government's initiatives for the rejuvenation of urban water bodies by endorsing the land use regulations on surrounding land uses.

Keywords: land use change; surface water resources; GIS; remote sensing; management and planning

1. Introduction

Water is a very essential commodity for human and nature's growth and development. UN world water development report 2019 presents that around one-third of the global population does not have access to safe drinking water [1], a continuously increasing gap between demand and supply of safe drinking water is a very serious issue in developing nations. The availability of safe water is directly related to the availability of safe and preserved surface water resources [2]. Surface water resources play a major role in fulfilling the supply–demand gap by recharging the groundwater, potential for rainwater harvesting, containing a large volume of water, reduction in urban flooding, treatment for wastewater by using constructed wetlands, etc. However, these resources are degraded by rapid haphazard, and unplanned land development [3]. So, there is a need to protect surface water resources through land use planning and surface water resources management for establishing a balance between water demand and supply in urban areas. The analysis of the effects of land use changes can be used to protect surface water resources, ensure the quality and quantity of surface water resources, reduce the pollutants level and place the sustainability of the resources [2,4]. Surface water resources' protection measures have been adopted in many developed countries such as rules/regulations on surrounding land use guidelines for delineating spatial boundaries in surrounding areas of water bodies in developed countries [5].

The influence of human activities on land use appears in the spatial distribution of natural resources in large-scale areas and it affects surface water resources. These effects are hydrological, morphological, and ecological such as changes in precipitation, infiltration, connectivity flow path, evapotranspiration, soil moisture, water storage, surface runoff volume, changes in properties, i.e., chemical, physical, biological, changes in sizes, basic shapes, volume, mean depth, water-resistance time, type/function, changes in phytoplankton composition, flora, fauna, etc. [6–22].

Various studies have presented that surrounding land uses of surface water resources are directly affecting the quantity and quality of water by disposing of chemicals, debris, and non-point pollutants [23–25]. Some studies have focused on the analysis of land use changes, trends, status, direction, and their effects on surface water resources. [17,26–39]. However, these studies do not cover comprehensive land use change research during long time periods, especially for high water-stressed regions in developing countries such as India.

There is a big issue to preserve urban surface water resources by analyzing land use changes and status and trends in India [3,40]. Some researchers have studied land use changes for the management of urban watersheds, river basins, lake basins, catchment area studies, etc. [25,40]. However, limited research studies have been completed on land use changes, status, trends, and directions of land use for NCT Delhi. This study aims to identify the relationships among land uses, and quantify the changes, status, trends, and directions for all land use types for one decade-wise and comprehensive decadal-wise results in Delhi. Land use change-based matrices are generated which have net changes, total changes, and P index for all land use types.

Before the colonial periods, India was rich in surface water resources aspect. There was an indigenous knowledge system for land–water–vegetation resources management in an intelligent and sustainable manner. Water bodies had ecological, environmental, social, and economic values, and like water bodies, their catchments were acquired for religious purposes and would not be polluted. Further, enormous, good production systems were possible by them, as one study by the Centre of Environment and Science, 1997. Later on, due to a change in land ownership from the local community to the government system, values and sense of belongingness towards water bodies and their catchments have been detached and the surface water resources have started degrading. Now, the conditions of these resources are very critical, most of them are disappearing due to encroachments in cities of India [41].

Delhi has become one of the most water-stressed cities in India after haphazard growth since the 1960s. In the past 62 years, the population has increased from 842,000 in 1981 to 32,066,000 in 2021. Since then, land use patterns have changed drastically due to rapid economic development in Delhi. An intensive increase in land uses is expected and subsequent changes are also occurring. These changes are affecting the ecosystem and sustainable development of the city. This study presents land use change and its effects in terms of trends, status, and patterns in Delhi over 30 years by using geographical information systems, remote sensing technology, and cross-tabulation metrics-based methods for 1991, 2011, and 2021 Landsat images. The analysis is completed based on extracted data and results are in quantified forms presenting that a built-up area is affecting other types of land uses, especially surface water resources and surface water resources land use is in extremely imbalanced status. This type of research study can be used for protecting surface water resources.

The study is comprised of a few sections such as the introduction, materials and methods, results, discussion, and conclusion. The introduction section contains the background information on land use changes and methods; based on the literature study gap analysis is shown; hypothesis and significance are also covered in this section. The materials and methods section discusses the study area in detail, the available number of water bodies based on surveys and their mapping, and the data sources subsection contains land use land cover changes maps prepared on GIS; the method section discusses all the methods, required definitions, and required equations. The result section covers all results of one decade and overall changes in metrics forms. Next, the discussion section describes the key findings, some unexpected results such as open/vacant land uses are decreasing due to built-up land use, few limitations, a way forwards and finally concluding with stating that water land use type is decreasing due to increasing built-up land use type. Further, the conclusion section is comprised of a brief overview and significance of the study, limitations, the importance of the study, and suggestions for relevant future studies.

2. Materials and Methods

2.1. Study Area

NCT Delhi is considered for analyzing land use changes, trends, status, and directions; the study area covers an area of 1483 km^2 as per the Master Plan of Delhi 2021. NCT Delhi is located between the coordinates of 76.84° E, 28.41° N, and 77.35° E, 28.88° N. In the geographic context, Delhi is situated between the Himalayas and Aravalis and the river Yamuna is on the eastern edge of the city shown in Figure 1. The topographical elevation is between 213 and 290 m in the city. The city is characterized by hot summers with maximum temperature reaching 45 °C and cold winters with minimum temperature reaching 1 °C. Rainfall is dependent on monsoon patterns with 800 mm/year occurring from June to September, which is decreasing yearly due to climate change [42].

Many large and small streams are carrying sewage water and falling into the Yamuna River which is the largest blue patch in the city. The fluctuation in groundwater levels shows between pre-monsoon and post-monsoon and most decreasing level is in southern parts of the city. At the present time, the groundwater level is decreasing by 1 cm every year in high groundwater-dependent areas [42]. As per Drainage Master plan 2031, Delhi has been divided into 3 major natural drainage sub-basins named Najafgarh, Barahpullah, and Trans-Yamuna basins [43].

NCT Delhi has fragmented natural features such as forest covers, greens, open areas, hills, water bodies, etc. Available surface water resources area is around 24.35 km^2 of total geographical area and mapping of surface water resources is shown in Figure 2, which is decreasing rapidly from 6.6% to 1.6% in the city as shown in Table 1. At present, city has around 1000 number natural and man-made water bodies [44–46]. These numbers are also varying based on different survey studies per 2001 survey of INTACH states 508, Tapas along with Court Commissioner states around 900, and the Green parks and Society (GNCTD) 2018 states around 1011 water bodies in Delhi [41].

Table 1. Surface water areas comparison based on master plans of Delhi [44–46].

S.no.	Master Plan	Total Geographical Area in km^2	Green Area in km^2	Green Area (%)	Surface Water Area in km^2	Surface Water Area (%)	No of Water Bodies	Area of Water Bodies (%)
1	1962	448	107.52	24	29.7	6.6	1449	6.4
2	2001	678	87.22	19	27.9	4.1	1166	3.8
3	2021	1483	104.70	14.16	24.35	1.6	969	0.8

Delhi is comprised of nine administrative districts—North West, North, North East, East, New Delhi, Central, West, South West, and South [47]. As per the CSE report made by M.Matto in 2017, available surface water bodies have the potential to hold 135MGD surface water but storage and water holding capacity of these water bodies have been decreasing. Earlier, these surface water resources were the sources of water supply but presently most of these are now converted into dump yards or collection yards of sewage. In Delhi, most of these resources are surrounded by high-density populated areas and few are surrounded by green/open/forest areas. The types of surrounding land uses are residential, recreational, industrial, commercial, green cover, open area, etc.

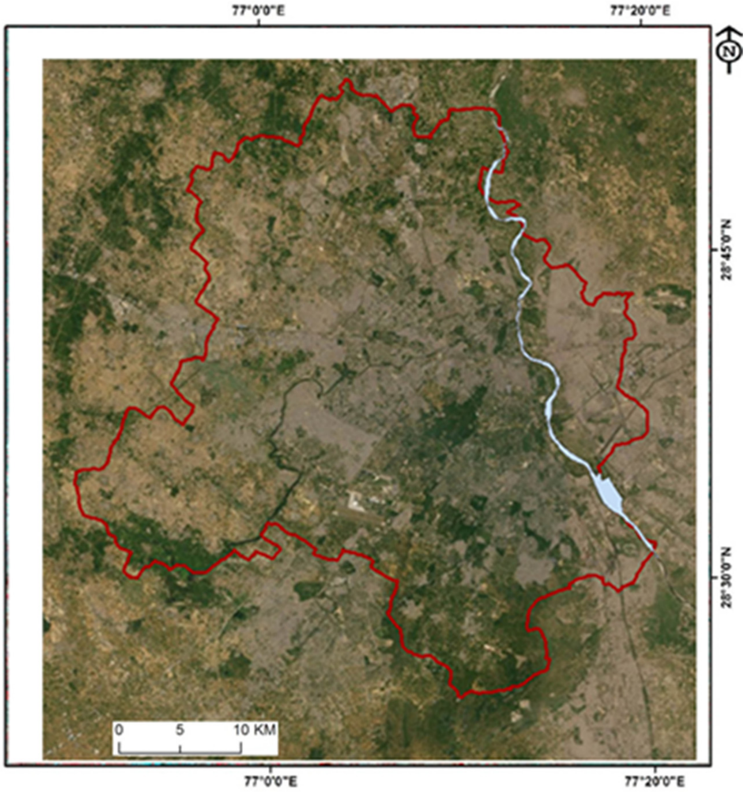

Figure 1. Satellite imagery of NCT Delhi, 2021. Source: author (2021).

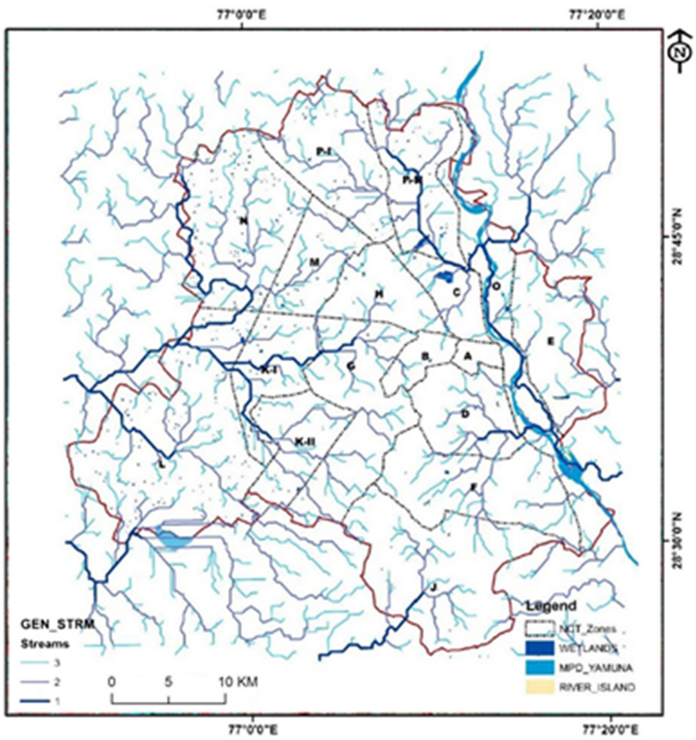

Figure 2. Mapping of surface water resources in NCT Delhi. Source: prepared on ArcGIS by author (2020).

For protecting these urban water bodies of Delhi, the central and state governments have enacted some rules and guidelines such as National Wetland Conservation Programme (1987), National Lake Conservation Plan (2001), Guidelines for Continuation of Scheme on Repair Renovation and Restoration of Water Bodies in 12th Plan (2005), National Water Mission under National Action Plan on Climate Change (2009), Wetlands (Conservation and Management) Rules (2010), Advisory on Conservation and Restoration of Water Bodies in Urban Areas by CPHEEO (2013), Atal Mission for Rejuvenation and Urban Transformation (2015), National Plan for Conservation of Aquatic Ecosystems (NPCA) (2016), Atal Bhujal Yojana (2019), Guidelines for Urban Water Conservation Jal Shakti Abhiyan (2019), City of Lakes Project for Rejuvenation of Water Bodies of Delhi (2019), etc.

2.2. Data Sources

Landsat thematic images are used for evaluating the land use changes and these datasets are extracted from USGS between 1991 and 2020. USGS datasets are processed by using ArcGIS tool for spatial-temporal consistency and reliability, the same projections and output extends are set in the conversion time from vector to raster dataset. Four LULC maps of years 1991, 2000, 2010, and 2020 are extracted and processed for changes, status, trends, and directions as shown in Table 2. These images have 30 m resolution with zero cloud cover satisfying the required precision for classification in ArcGIS. Following Landsat scenes are used for land use classification:

Table 2. Details of data sources. Source: author (2020).

S.no.	Year	Satellite	Collection Date and Year
1.	1991	Landsat-5 (TM)	5 March 1991 and 14 March 1991
2.	2000	Landsat-5 (TM)	19 February 2000
3.	2010	Landsat-5 (TM)	14 February 2010 and 21 February 2010
4.	2020	Landsat-8 (TM)	10 February 2020 and 17 February 2020

3. Methods

There are four land use types in the study area such as built up, water body, green/vegetation/forest, and barren/open land. The compilation of maps is based on map generalization method. Initially, the study formulated a classification for four land use types then the study compiled maps for four periods by reclassifying the land use types into six patch types and combining the polygons with the same type. For the classification work, supervised classification methods with maximum likelihood algorithm are applied on GIS 10.3. Classification results are generated by creating normalized difference vegetation index, normalized difference water index (NDWI), and normalized difference built-up index (NDBI) indices. After generating land use change maps, analysis is performed for the changes (net change, total change), trends, and status and the results are presenting the decreasing trend in water body land use type.

For improving the processing precision of data interpretation, land use information investigation is carried out in 2000 and 2010. Relying on USGS datasets is based on professional knowledge which is 80% and 87%, respectively, accurate, for avoiding discrepancies two measures are used such as repeated interpretation by two or three professionals and field verification further kappa coefficients are used. A uniform classification and accuracy-providing measures give the accuracy of USGS dataset's spatial-temporal distribution which lays out the basis for study.

There is a need to understand the land use changes, trends, and status for planning and management of surface water resources [48]. The detailed analysis of land use changes is completed by using cross-tabulated matrices method, because this method helps in characterizing the temporal changes [49–51]. An effective and detailed analysis of land use changes has some important features such as net change, total change, status, direction, and trends (STD) [50,51]. These features are processed from the data prepared on Arc GIS in the forms of maps and excel datasheets.

By using cross-tabulated method, land use changes, trends, status, and directions have been presented. Here, the definitions of these terms are described below:

Net change(Nc): It is defined as the maximum gain or loss minus the minimum gain or loss for each land category in a time period [49,51].

Total change(Tc): It is defined as the sum of gain or loss of an area [49].

Status, Trends, Direction (STD): It is described by the comprehensive index P for land use types [49].

The status reflects the land change dynamics; its' four types are defined as balanced (loss equals gain of an area for a particular land use type), quasi-balanced (slight inequality between loss and gain), unbalanced (significant difference between loss and gain), and extremely unbalanced status [40].

The trend refers to if a land type has a positive or negative change. A rising or falling trend is assigned to the land use type that expands or contracts in size. If no such changes are detected, the trend is regarded as zero. [40,50,51].

Direction is defined as either one-way or two-way transition, and it is used to characterize the process of land losses and gains for a land use type.

In the following sections, the quantitative values are calculated for both the individual and the entire land types as a whole to better characterize the land change.

3.1. Changes, Status, Trends, and Directions for Individual Land Types

Land use changes can be expressed by using net change and total change for a land use type. Net change is the areal change in land use type and it results from an interplay between this land type and another involved land type. The sum of the loss and gains for a particular land type shows the intensity of land transitions. Here, let us assume a land type has changed from *Lstart* to *Lend* in a certain time period, then net change (NC) and total change (Tc) are explained as:

$$\begin{aligned} Nc &= (Lend - \ Lstart) \ \times 100\% \div Lstart \\ &= (\Delta Lin - \Delta Lout) \ \times 100\% \div Lstart \end{aligned} \quad (1)$$

$$Tc = (\Delta Lin + \Delta Lout) \times 100\% \div Lstart \quad (2)$$

where *Lstart* and *Lend* indicate the area of a land class at the start and end of the comparison period, respectively. ΔLin *and* $\Delta Lout$ Indicate the area that changed from other land classes to a land class within the period (gain) and the total area changed from one land class to other land classes (loss), respectively.

ΔLin (≥ 0) presents the lands of a particular land type gained or converted to other land types over the time period, $\Delta Lout$ (≥ 0) presents the total lands lost or converted to that particular land type from other land types [40,49,51].

Equations (1) and (2) are simpler and easier to use. By using these equations, P index is expressed to present the status, trend, and direction of a land use type:

$$\mathrm{P} = \mathrm{Nc} \div \mathrm{Tc} \qquad -1 \leq \mathrm{P} \leq 1, \qquad \Delta Lin + \Delta Lout \neq 0 \quad (3)$$

If $\Delta Lin + \Delta Lout = 0$, this situation comes where a land type has not undergone any change, this equation is not relevant. When $\Delta Lout = 0$ and $\Delta Lin \neq 0$ i.e., $\mathrm{P} = 1$, it is meaning that a particular land use type has gained land from another land type without any loss; when $\Delta Lin = 0$ and $\Delta Lout \neq 0$ i.e., $\mathrm{P} = -1$ it means that a particular land type has decreased without any gain. In these situations, a particular land type identified by one-way transitions with an extremely imbalanced status, and when $\Delta Lin = \Delta Lout \neq 0$ i.e., P = 0, it is meaning that change is balanced and two-way transitions as shown in Table 3.

If $0 < P \leq 1$, the index suggests that land use changes are an increasing trend. High P value close to 1 shows one-way transition for a land use type. This land type consumes other land types, and it shows land type expansion and an imbalanced status. Low P value closes to -1 shows quasi-balanced, two-way transition for a land use type and land type has converted into another land type. If P near zero shows the land has converted into another land type but the loss may be compensated by gains from other land types as shown in Table 3.

If $-1 \leq P < 0$, a particular land type is decreasing in negative change and trend if P leads towards -1 it shows a one-way transition, extremely imbalanced, negative change trend status; if P is near to 0 it shows that land type is decreasing small, two-way transition and balanced status [50] as shown in Table 3.

3.2. Changes, Status, Trends, and Directions for All Land Types in Whole Region

It is similar to above, the net changes Ncs, total changes Tcs, and Ps for whole region can be calculated by given equations [40,49].

$$\begin{aligned}\mathrm{Ncs} &= \frac{\sum_{i=1}^{n}|Lend\ i - Lstart\ i|}{2\sum_{i=1}^{n} Lstart\ i} \times 100\% \\ &= \frac{\sum_{i=1}^{n}|Lin\ i - Lout\ i|}{2\sum_{i=1}^{n} Lstart\ i} \times 100\%\end{aligned} \tag{4}$$

$$\mathrm{Tcs} = \frac{\sum_{i=1}^{n}(Lin\ i + Lout\ i)}{2\sum_{i=i}^{n} Lstart\ i} \times 100\% \tag{5}$$

Here, Ncs are indices of Nc for all land use types and Tcs are indices of Tc for all land use types for whole NCT Delhi. *Lstart i, Lend i, Lin i, Lout i* present the areas of the initial stage, final stage, gain, and loss for the land use type in i period, respectively. n is the total number of land use types in NCT Delhi. Using Equations (4) and (5), index Ps is presented the status, trends, and directions of land use changes for NCT Delhi:

$$\mathrm{Ps} = \frac{\mathrm{Ncs}}{\mathrm{Tcs}} = \frac{\sum_{i=i}^{n}|Lend\ i - Lout\ i|}{\sum_{i=1}^{n}(Lin\ i + Lout\ i)} \qquad 0 \leq \mathrm{Ps} \leq 1, \quad \mathrm{Tcs} \neq 0 \tag{6}$$

If Ps is 0, the region has balanced, two-way transition, if Ps is towards 1 or -1, the region has imbalanced, one-way transition. The given below table is presenting the 8 different type of relationship between Ps index and STD [48,50].

Table 3. Relationship between Ps index and status, trends and directions [49–52].

S.no.	Value of Index Ps	Status	Trend	Direction
1.	$-1 \leq$ Ps< -0.075	Extremely imbalanced	Negative change	One-way transition
2.	$-0.75 \leq$ Ps < -0.50	Imbalanced	Negative change	One-way transition
3.	$-0.50 \leq$ Ps < -0.25	Quasi-balanced	Negative change	Two-way transition
4.	$-0.25 \leq$ Ps < 0	Balanced	Negative change	Two-way transition
5.	$0 \leq$ Ps < 0.25	Balanced	Positive change	Two-way transition
6.	$0.25 \leq$ Ps < 0.50	Quasi-balanced	Positive change	Two-way transition
7.	$0.50 \leq$ Ps < 0.75	Imbalanced	Positive change	One-way transition
8.	$0.75 \leq$ Ps < 1	Extremely imbalanced	Positive change	One-way transition

Status, direction, and trend are closely related, like a balanced status indicates two-way transition, whereas an imbalanced and extremely imbalanced status is normally associated with one-way transition. The trends are negative for falling for first half from extremely imbalanced to balanced and positive for rising for second half from balanced to extremely imbalanced as shown in Table 3.

4. Results

Changes, Trends and Status of Land Use

The land use change maps have derived from image classification in NCT Delhi from 1991 to 2020 as shown in Figure 3. The analysis process has performed by a post-classification detection method, a cross-tabulated matrix statistical analysis has been conducted: built-up (52.95%) land use type is the largest land type followed by vacant land (24.73%), vegetation land (21.39%) and water bodies (0.92%) in the NCT Delhi based on analysis as shown in Figure 3, Figure 4 and Table 4. Built-up land use type has increased and water bodies' land use type has decreased in last 30 years. Built-up land use is distributed evenly in the central part of the city and spreading in an outward direction and vegetation, open land uses are distributed in the periphery of the city.

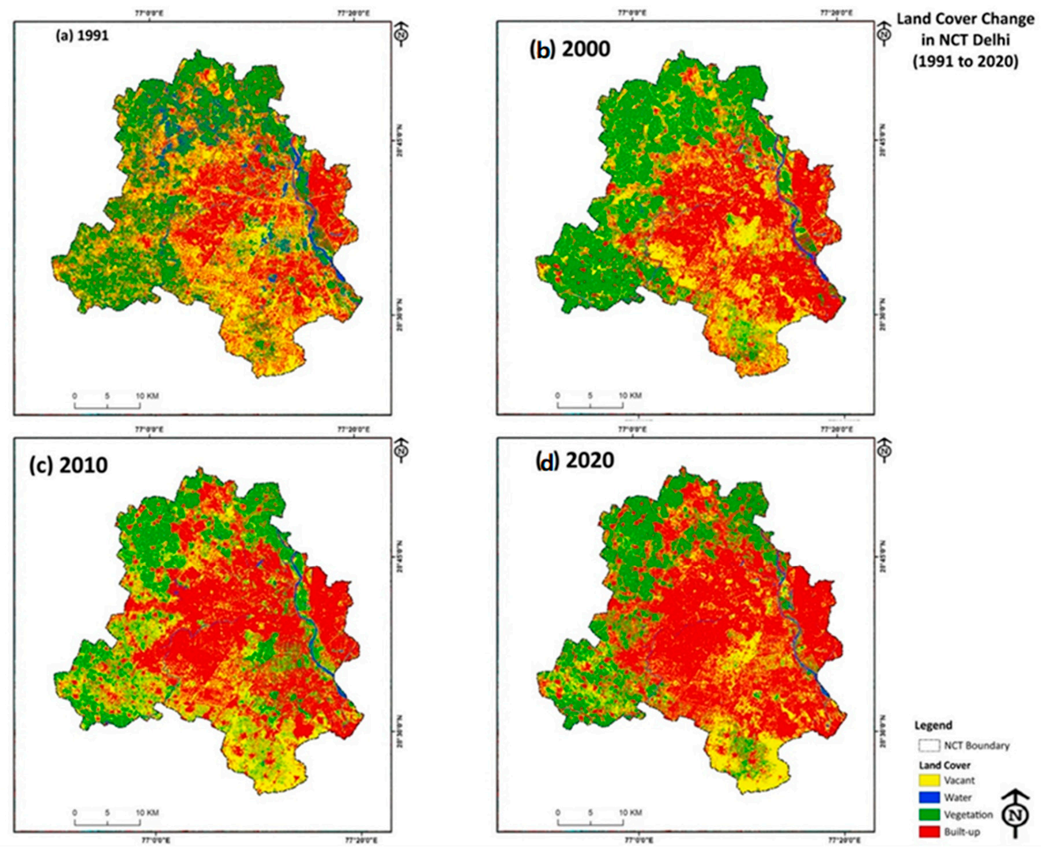

Figure 3. Land use and land cover changes in NCT Delhi from 1991 to 2020 (**a**–**d**). Source: author (2020).

In all the periods, the extent of vegetation, vacant areas, and water bodies decreased because these areas are converted into built-up land use types. From 1991 to 2020, the built-up land use area increased by 271.18 km^2. In the decades 1991–2000, 2000–2010, 2010–2020, and 1991–2020, the built-up area is increasing at rates of 5.47, 11.19, 10.99, and 27.11 km^2/year, respectively. The extent of water bodies has decreased by 37.51 km^2 and decreasing rates in decades 1991–2000, 2000–2010, 2010–2020, and 1991–2020 are 3.73, 0.24, 0.15, and 1.29 km^2/year, respectively. The extent of vegetation land use has decreased by 110.26 km^2 and in decades, 1991–2000, 2000–2010, 2010–2020 and 1991–2020 vegetation is decreasing at rates of 4.77, 12.77, 2.54, and 11.02 km^2/year, respectively. The extent of vacant land use has decreased by 123.39 km^2 and in decades 1991–2000, 2000–2010, 2010–2020 and 1991–2020 vacant land is decreasing at rates of 6.51, 1.82, 8.29, and 12.33 km^2/year, respectively shown in Table 4 and Figure 4. Built-up land use is increasing due to the expansion of urban areas and towns in NCT Delhi.

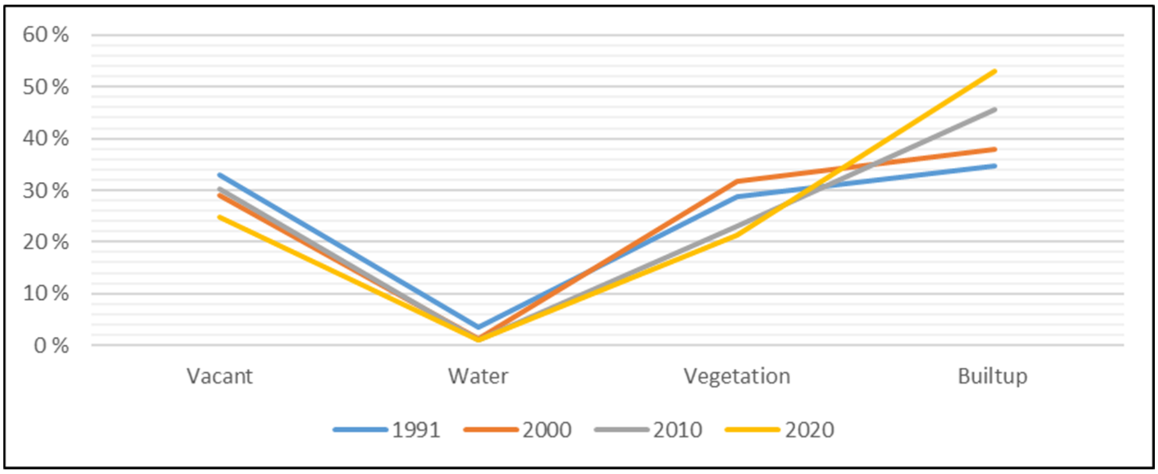

Figure 4. Percentage of estimated area of land-use categories and their changes in NCT Delhi in 1991, 2000, 2010, and 2020. Source: author (2020).

Table 4. Changes in land use in NCT Delhi from 1991 to 2020. Source: author (2020).

Year	Statistic Type	Land Use				Total Area (km^2)
		Vacant Land	Water Land	Vegetation Land	Built-Up Land	
1991	Area (km^2)	490.20	51.22	427.47	514.11	1483.00
	%	33.05	3.45	28.82	34.67	100.00
2000	Area (km^2)	431.57	17.68	470.41	563.35	1483.00
	%	29.10	1.19	31.72	37.99	100.00
2010	Area (km^2)	449.80	15.22	342.65	675.34	1483.00
	%	30.33	1.03	23.10	45.54	100.00
2020	Area (km^2)	366.81	13.71	317.21	785.29	1483.00
	%	24.73	0.92	21.39	52.95	100.00
1991–2000	Land use change (%)	−6.51	−3.73	4.77	5.47	
2000–2010	Land use change (%)	1.82	−0.24	−12.77	11.19	
2010–2020	Land use change (%)	−8.29	−0.15	−2.54	10.99	
1991–2020	Land use change (%)	−4.25	−1.29	−3.8	9.35	
1991–2020	Change in Area of land use (km^2)	123.39	37.51	110.26	271.18	

Decadal-wise maps as shown in Figure 3 are prepared. Cross-tabulation matrices are produced with the help of a pivot table that shows the area of the landscape for each combination of categories in decades as shown in Tables 5–8. Firstly, there is a need to analyze the matrices shown in Tables 5–8 for examining the total column and the total row for showing the largest land use type which is built up in all three decades. Further, there is a need to examine the diagonal entries in tables. Diagonal entries are used for finding gains and losses as shown in Tables 5–8. These tables give additional information for concerning gain, loss, persistence, and swap.

Table 5. Matrix presents percent of land change in terms of losses and gains from 1991 to 2000. Source: author (2020).

		2000					
		Vacant Land	**Water Land**	**Vegetation Land**	**Built-Up Land**	**Total 1991**	**Loss**
1991	Vacant land	217.24	3.36	86.49	183.32	490.20	272.96
	Water land	15.68	9.51	19.66	6.59	51.22	41.71
	Vegetation land	93.84	2.97	290.14	40.74	427.47	137.33
	Built-up land	104.81	1.83	74.12	332.69	514.11	181.42
	Total 2000	431.57	17.68	470.41	563.35	1483.00	633.42
	Gain	214.33	8.17	180.27	230.66	633.43	

Note: unit is km^2.

Above matrix shown in Table 5 has been prepared for showing the land use changes from 1991 to 2000. The total land uses area has been identified for 1991 and 2000. Further diagonal entries are identified and highlighted in the table. For finding gain and loss, there is a need to subtract that particular land use type's diagonal entry from the total of that particular land use type such as loss in vacant land is 272.96 km^2 (490.20 − 217.24 = 272.96 km^2) and gain in vacant land is 214.33 km^2 (413.57 − 217.24 = 214.33 km^2), loss in water land is 41.71 km^2 (51.22 − 9.51 = 41.71 km^2) and gain in water land is 8.17 km^2 (17.68 − 9.51 = 8.17 km^2), loss in vegetation land is 137.33 km^2 (427.47 − 290.14 = 137.33 km^2) and gain in vegetation land is 180.27 km^2 (470.41 − 290 = 180.27 km^2). Finally, the loss in built-up land is 181.42 km^2 (514.11 − 332.69 = 181.42 km^2), and the gain in built-up land is 230.66 km^2 (563.35 − 332.69 = 230.66 km^2). The loss and gain of land use have been presented in Figure 5 for the 1991-2000 decade.

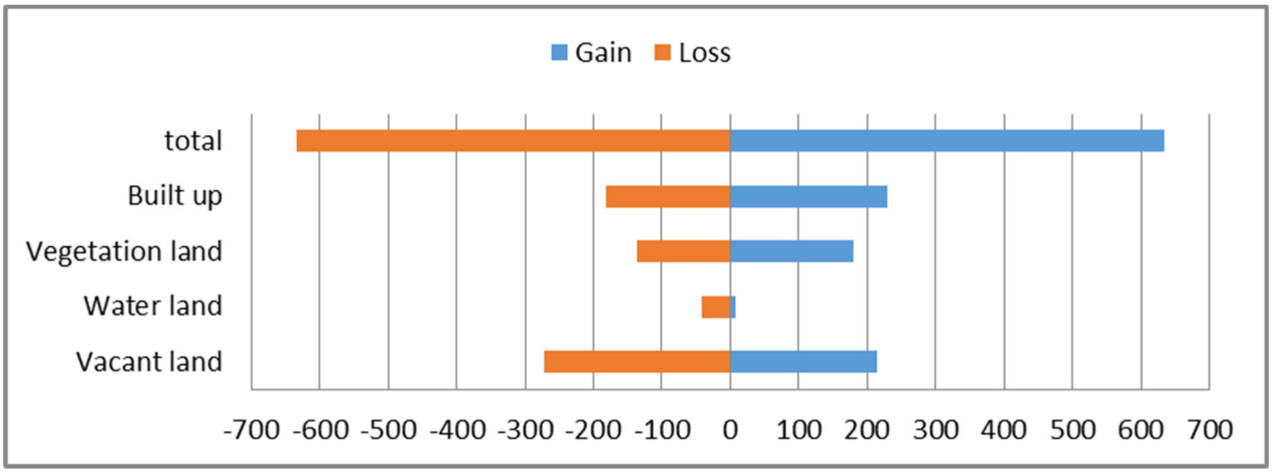

Figure 5. Gain and loss in areas from 1991 to 2000. Source: author (2020).

Table 6. Matrix presents percent of land change in terms of losses and gains from 2000 to 2010. Source: author (2020).

		2010					
		Vacant Land	**Water Land**	**Vegetation Land**	**Built-Up Land**	**Total 2000**	**Loss**
2000	Vacant land	187.61	1.98	81.85	160.35	431.57	243.96
	Water land	2.23	8.66	3.15	3.86	17.68	9.02
	Vegetation land	167.89	1.44	230.38	70.92	470.41	240.03
	Built-up land	92.06	3.15	27.26	440.22	563.35	123.13
	Total 2010	449.80	15.22	342.65	675.34	1483.01	616.14
	Gain	262.19	6.56	112.27	235.12	616.14	

Note: unit is km^2.

Above matrix as shown in Table 6 has been prepared for showing the land use changes from 2000 to 2010. The total land uses area has been identified for 2000 and 2010. Further diagonal entries are identified and highlighted in the table. For finding gain and loss, there is a need to subtract that particular land use type's diagonal entry from the total of that particular land use type such as loss in vacant land is 243.96 km^2 (431.57 − 187.61 = 243.96 km^2) and gain in vacant land is 262.19 km^2 (449.80 − 187.61 = 262.19 km^2), loss in water land is 9.02 km^2 (17.68 − 8.66 = 9.02 km^2) and gain in water land is 6.56 km^2 (15.22 − 8.66 = 6.56 km^2), loss in vegetation land is 240.03 km^2 (470.41 − 230.38 = 240.03 km^2) and gain in vegetation land is 112.27 km^2 (342.65 − 230.38 = 112.27 km^2). Finally, the loss in built-up land is 123.13 km^2 (563.35 − 440.22 = 123.13 km^2), and the gain in built-up land is 235.12 km^2 (675.34 − 440.22 = 235.12 km^2). The loss and gain of land use have been presented in Figure 6 for the 2000–2010 decade.

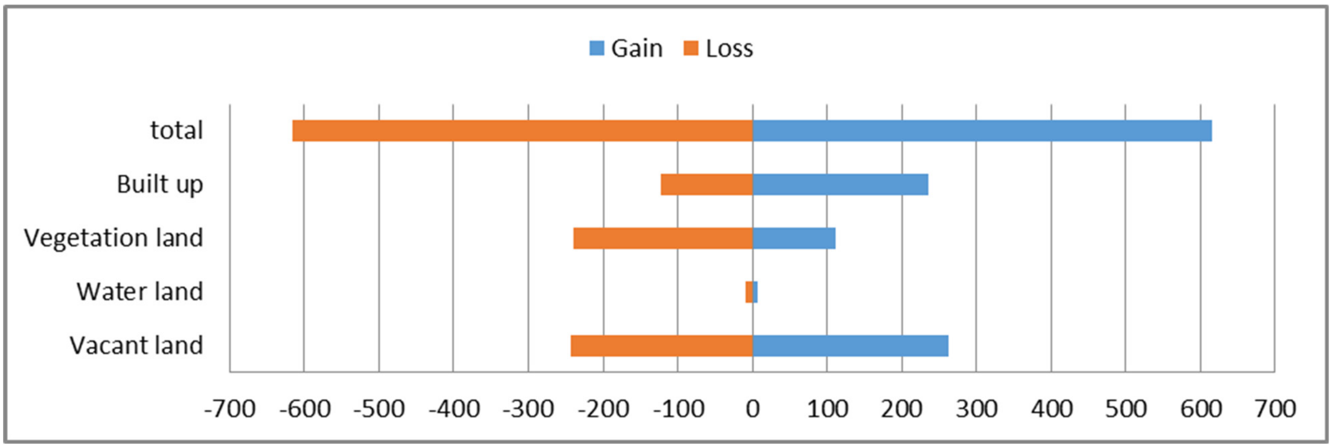

Figure 6. Gain and loss in areas from 2000 to 2010. Source: author (2020).

Table 7. Matrix presents percent of land change in terms of losses and gains from 2010 to 2020. Source: author (2020).

		2020					
		Vacant Land	**Water Land**	**Vegetation Land**	**Built-Up Land**	**Total 2010**	**Loss**
2010	Vacant land	194.81	1.39	93.86	159.96	449.80	254.99
	Water land	1.58	8.45	1.33	4.09	15.22	6.77
	Vegetation land	95.88	2.06	203.13	41.80	342.65	139.52
	Built-up land	74.54	1.82	18.88	579.44	675.34	95.90
	Total 2020	366.81	13.71	317.21	785.29	1483.01	497.18
	Gain	172.00	5.26	114.08	205.85	497.18	

Note: unit is km^2.

Above matrix as shown in Table 7 has been prepared for showing the land use changes from 2010 to 2020. The total land uses area has been identified for 2010 and 2020. Further diagonal entries are identified and highlighted in the table. For finding gain and loss, there is a need to subtract that particular land use type's diagonal entry from the total of that particular land use type such as loss in vacant land is 254.99 km^2 (449.80 − 194.81 = 254.99 km^2) and gain in vacant land is 172.00 km^2 (366.81 − 194.81 = 172.00 km^2), loss in water land is 6.77 km^2 (15.22 − 8.45 = 6.77 km^2) and gain in water land is 5.26 km^2 (13.71 − 8.45 = 5.26 km^2), loss in vegetation land is 139.52 km^2 (342.52 − 203.13 = 139.52 km^2) and gain in vegetation land is 114.08 km^2 (317.21 − 203.13 = 114.08 km^2). Finally, the loss in built-up land is 95.90 km^2 (675.34 − 579.44 = 95.90 km^2), and the gain in built-up land is 205.85 km^2 (785.29 − 579.44 = 205.85 km^2). The loss and gain of land use have been presented in Figure 7 for the 2010–2020 decade.

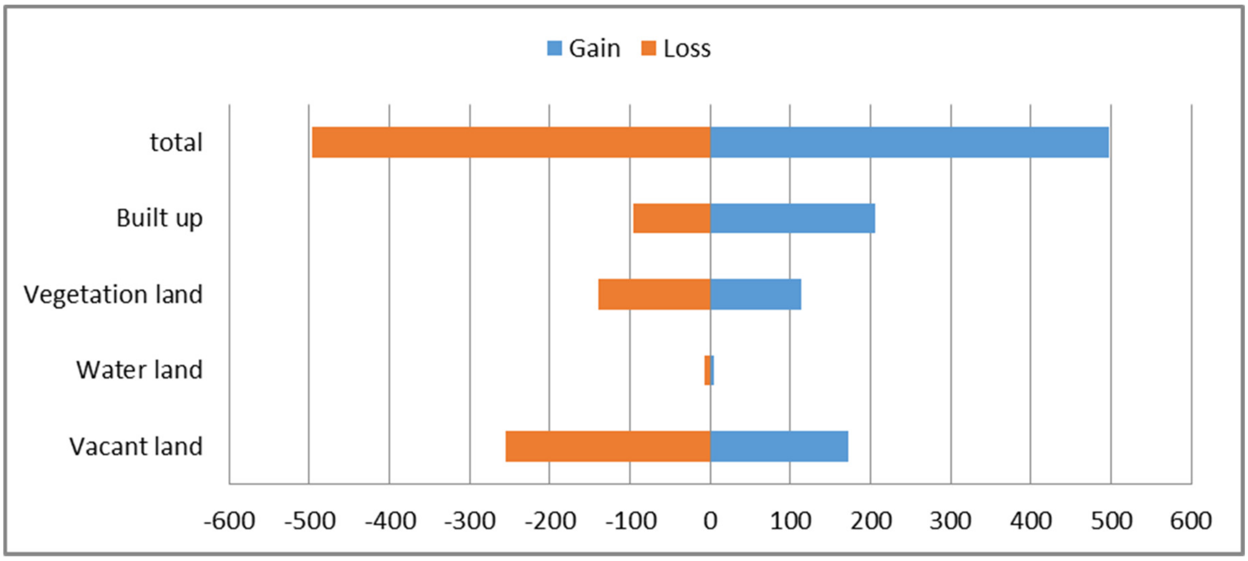

Figure 7. Gain and loss in areas from 2010 to 2020. Source: author (2020).

Table 8. Matrix presents percent of land change in terms of losses and gains from 1991 to 2020. Source: author (2020).

		2020					
		Vacant Land	**Water Land**	**Vegetation Land**	**Built-Up Land**	**Total 1991**	**Loss**
1991	Vacant land	160.45	2.29	54.95	272.51	490.20	329.75
	Water land	15.25	7.89	15.23	12.85	51.22	43.33
	Vegetation land	112.81	2.39	198.38	113.90	427.47	229.09
	Built-up land	78.52	1.35	48.87	385.37	514.11	128.74
	Total 2020	366.81	13.71	317.21	785.29	1483.00	730.91
	Gain	206.36	5.82	118.83	399.92	730.92	

Note: unit is km^2.

Above matrix as shown in Table 8 has been prepared for showing the land use changes from 1991 to 2020. The total land uses area has been identified for 1991 and 2020. Further diagonal entries are identified and highlighted in the table. For finding gain and loss, there is a need to subtract that particular land use type's diagonal entry from the total of that particular land use type such as loss in vacant land is 329.75 km^2 (490.20 − 160.45 = 329.75 km^2) and gain in vacant land is 206.36 km^2 (366.81 − 160.45 = 206.36 km^2), loss in water land is 43.33 km^2 (51.22 − 7.89 = 43.33 km^2) and gain in water land is 5.82 km^2 (51.22 − 7.89 = 5.82 km^2), loss in vegetation land is 229.09 km^2 (427.47 − 198.38 = 229.09 km^2) and gain in vegetation land is 118.83 km^2 (317.21 – 198.38 = 118.83 km^2). Finally, the loss in built-up land is 128.74 km^2 (514.11 − 385.37 = 128.74 km^2), and the gain in built-up land is 399.92 km^2 (785.29 − 385.37 = 399.92 km^2). The loss and gain of land use have been presented in Figure 8 for the 1991-2020 decade. This result presents that the built-up has the largest gain 399.92 km^2 of the area and vacant land has the largest loss 329.75 km^2 of the area from the 1991 to 2020 timeline.

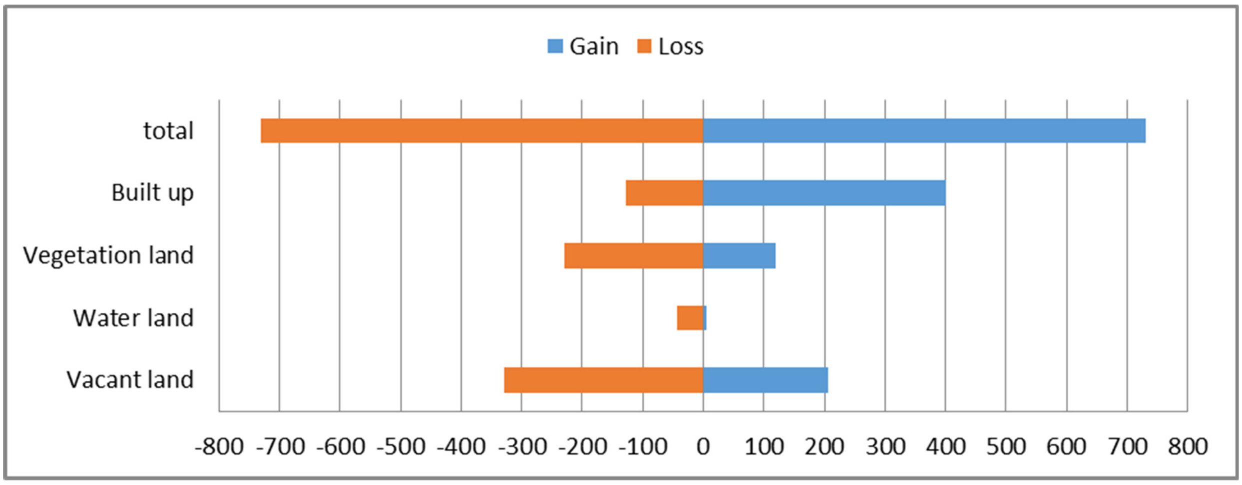

Figure 8. Gain and loss in areas from 1991 to 2020. Source: author (2020).

Further, the discussed methods have been used to analyze the land use changes, trends, status, and directions in NCT Delhi for 1991–2000, 2000–2010, 2010–2020, and 1991–2020. In Tables 9 and 10, the net change (Nc), total change (Tc), and index(P) for individual land use type and net change (Ncs), total change (Tcs), and index (Ps) for the whole region are described, respectively.

Table 9. Change trends of land-uses use from 1991 to 2020. Source: author (2020).

Timeline	Index	Land Use Type			
		Vacant Land	Water Land	Vegetation Land	Built-Up Land
1991–2000	Nc(%)	−11.96	−65.48	10.04	9.57
	Tc(%)	99.40	97.38	74.29	80.15
	P	−0.12	−0.67	0.13	0.11
2000–2010	Nc(%)	4.22	−13.91	−27.15	19.87
	Tc(%)	117.28	88.12	74.89	63.59
	P	0.035	−0.15	−0.36	0.31
2010–2020	Nc(%)	−18.45	−9.92	−7.42	16.28
	Tc(%)	94.92	79.04	74.01	44.68
	P	−0.19	−0.12	−0.1	0.36
1991–2020	Nc(%)	−25.17	−73.23	−25.79	52.74
	Tc(%)	109.36	95.95	81.39	102.83
	P	−0.23	−0.76	−0.31	0.51

Table 10. Change trends of land- use type in NCT Delhi from 1991 to 2020 for the NCT Delhi. Source: author (2020).

Index	1991–2000	2000–2010	2010–2020	1991–2020
Ncs (%)	6.21	8.78	7.41	18.28
Tcs(%)	42.71	41.54	33.52	49.28
Ps	0.145	0.21	0.22	0.37

Tables 9 and 10 show the landuse change trends decadal-wise for every land use type. In the decade 1991–2000 as shown in Tables 9 and 10, the total change for the whole region is 42.71% which shows the conversion of land use types accounting for 42.71% of the whole area. This resulted in a net change of 6.21%, in this period individual land use type shows that built-up and vegetation land use types have been expanded and water bodies, and vacant land use types have been shrunk. In this period, the Ps index shows a 0.145 value which indicates changes are balanced, two-way transition, and positive changes. Based on values of land use types, vacant land use type shows balanced, two-way transition and negative changes; water land use type shows imbalanced, one-way transition and negative change; vegetation land use type shows balanced, two-way transition and positive change; and built-up land use shows balanced, two-way transition and positive change. This change in trend shows that water body land use type is decreasing and converted into vegetation and built-up land use types.

Further, in the decade 2000–2010 as shown in Tables 9 and 10, total change is 41.54% and net change is 8.78% for the whole region. In this timeline, individual land types, built-up, and vacant land types are expanding and vegetation and water bodies are shrinking. Vacant land is expanding at a slow rate. Ps index is 0.21 slightly increased, which presents that the change is balanced, with two-way transition and positive changes. P values for vacant, water, and built up is increased but for vegetation is decreased. Based on P values of land use types, vacant land use type shows balanced, two-way transition and positive changes; water body land use type shows balanced, two-way transition and negative changes; vegetation land use type shows quasi-balanced, two-way transition and negative changes; and built-up land use type shows quasi-balanced, two-way transition and positive changes.

In the decade, 2010–2020 as shown in Tables 9 and 10, a net change is 7.41% and the total change is 33.52% for the whole region. Individual land type water bodies, vegetation, and vacant land use types are shrinking, and built-up land type is expanding. Ps index is 0.22 slightly increased, which presents the change is balanced, with two-way transition and positive changes. P values for vacant land use type are decreased but water, vegetation, and built-up are increased. Based on P values of land use types, vacant land use type shows balanced, two-way transition and negative changes; water land use type shows balanced, two-way transition and negative changes; vegetation land use type shows balanced, two-way transition and negative changes; built-up land use type shows quasi-balanced, two-way transition and positive changes. All the P values of every land use type have increased but for built-up, it has changed from 0.11 to 0.51.

In the entire period timeline 1991–2020 as shown in Tables 9 and 10, individual land use types of vacant land, water bodies, and vegetation are shrinking and built-up is expanding. Water body land use type is shrinking rapidly. In this major timeline, the net change is 18.28% and the total change is 49.28% for the whole region. In the whole study, the land use change trends (P = 0.37) present quasi-balanced, two-way transition and positive changes. This value is much higher than the three periods because it is the longer period and has a higher sum of changes. The P value of the built-up (0.51) is the largest with vegetation land and vacant land use types having smaller and water land use type having the smallest.

Based on the above statistical analysis, NCT Delhi has a quasi-balanced status and trends of land use as shown in Tables 3 and 10. This phenomenon is happening due to increasing built-up area due to human activities and climate changes (decreasing in surface water resources area). As per analysis, water land use type is converted into vacant land, smaller vegetation land, and built-up land use types.

5. Discussion

This study is conducted to analyze the land use changes, trends, status, and directions of all land use types, especially water body land use type in NCT Delhi to set an alarm for protecting remaining urban water bodies. The results are showing that land uses have changed in varied forms from 1991 to 2020 with quasi-balanced, two-way transition and positive changes in the NCT boundary The P value for water body land use type is -0.76 which is showing extremely imbalanced, negative change, and one-way transition which means that water body land use type is the smallest type and decreasing rapidly. Another land use type such as built-up has the highest P value of 0.51, which is showing imbalanced, positive change and one-way transition which means that the built-up land use type is the largest type and increasing rapidly and directly affecting the water body land use type. Human activities are one of the driving forces for land use change in the short term and other phenomena such as climate change affect the long-term [50].

Few studies have focused on the analysis of land use changes, trends, status, direction, and their effects on water bodies [27,28,30,33–35]. However, these studies are not looking at a comprehensive land use changes research study during long time periods for protecting water bodies. Previous studies are targeting land use changes, status, trends, and directions in particular basin areas but there is no study to identify the relationships among land uses, quantify the changes, status, trends, and directions for all land use types one decade-wise, and comprehensive decadal-wise for especially looking at surface water resources in water-stressed cities such as Delhi. This study will provide guidance to planners and development authorities to take concern about water bodies in the city during development planning.

In the past 30 years, the population has grown drastically in the city; this growth caused the need for basic necessities for people. This ultimately impacts the available resources. A large extent of the open and green area has been modified since the 1962 Master Plan. The built-up area has been increasing very rapidly. Natural resources have been affected by this change in this region. The decline in natural resources has a negative impact on efforts to preserve the stability of this region. These issues have been attended by various researchers, and this study also presented that land use change driven by natural and human activities has affected natural resources.

Since 1962, land use conversion has been taking place by locals, industrialists, and other development causes. These have put a significant influence on spatial and temporal differences in land use conversion, and other environmental effects. Water body uses and types are also changed which is affecting the groundwater level. Economic activities and residential built-up are important to grow the economy of any city. There is the fastest-growing economic development in NCT Delhi. Along with this, land and water resources are also the most demanding resources. This phenomenon is leading to larger uses of available water resources. These days, the groundwater level is increasing very rapidly and on average, the water level in Delhi is around 10 mgbl [42]. This region has different types of water resources such as rivers, drains, nallahs, ponds, lakes, etc., but most of them are not playing their actual role in improving the water quality and quantity.

The study used indices P and Ps for characterizing spatial changes. P, and Ps have numerators that represent the temporal land use changes and denominators that represent spatial changes. Using net change, total change, and P index in the study, the temporal and spatial changes can be determined for expansion of built-up areas, encroachment over water bodies and conversion of land uses such as in the periods 1991–2000, 2000–2010, 2010–2020, 1991–2020; P values -0.67, -0.15, -0.12, -0.76 for water bodies, respectively, presenting land use is decreasing in the study area as shown in Table 9. For built-up land use, P values 0.11, 0.31, 0.36 and 0.51 for the periods 1991–2000, 2000–2010, 2010–2020, 1991–2020 increasing, respectively, presenting land use is increasing in the study area as shown in Table 9. Water body area is decreased by -0.76% and quality is affected by surrounding land uses in form of non-point pollution sources. Unplanned built-up land use type can induce water pollution contents. From 1991 to 2020, vacant land decreased by 123.39 km^2; the change was a balanced, two-way transition. Due to the increase in built-up land use type, water land use type is decreasing, so groundwater level is also shrinking which is 37.51 km^2 and change is imbalanced, one-way transition. The built-up land use type is increasing by 271.18 km^2 and the change is an imbalanced one-way transition. The change in built-up land is influenced by other land use types decreasing, and the unplanned settlements increasing.

Based on the above discussion, change in land use can help in improving water quality levels like large green areas impact water quality and quantity. These areas need to plan for making buffer zones and to be incorporated into the layout plan. Eventually, the built-up areas need to be developed in control manner so fragmentation can be reduced. The vacant land can be converted into a vegetation land type for increasing green cover and enhancing the groundwater level. This study presents a useful method for sustainable developments where major land use changes occur. Illegal and haphazard developments of built-up land types is happening without following the norms of development plans since 2001 in Delhi. Rapid expansion has been seen in residential and new construction areas over dried-up water bodies, green areas, and open or vacant sites in the city. In the past 30 years, over-extraction of groundwater, misuse of water bodies and rainwater, and built-up area expansion are a few factors that are affecting surface water resources.

The strength of this study is that it is a comprehensive study for analyzing land use changes for protecting water bodies in developing countries. Planners can use this study for identifying the water bodies incorporated as an important element in the master plan. By using this, water bodies can be saved for the future. There are a few limitations of this study such as time and accuracy of data. Because of this changes in landscape patterns are not generated for NCT Delhi. In concluding remarks, this analysis study is useful for analyzing land use changes and knowing the effects of these changes. After understanding the changes, and effects, vulnerable land use types will be able to be protected by using available guidelines and methods. The significance of the study is to protect urban water bodies which are in a vulnerable state in developing countries.

This complete information can be provided to land use planners and surface water resource managers for protecting urban surface water resources. These sets of phenomena are ascribed to policies and guidelines for protecting water resources. These trends, status, and changes are featured for the policies, plans, schemes, and guidelines of national, state, and local level jurisdictions for the protection and conservation of surface water resources. Some projects such as the city of lakes, rejuvenation of water bodies, etc., are placed for strengthening groundwater level, enhancing water supply, and reducing water pollution in Delhi.

6. Conclusions

This study can be useful for protecting urban water bodies from other land use types, especially built-up types by analyzing land use changes, trends, status, and directions. This study provides the opportunity for improving the capability of planners to formulate significant policies and plans.

Remote sensing, geographical information system technology, and cross-tabulation methods have been used in this study and calculated net change, total change, trends, status, and directions for individual land uses and for the whole NCT Delhi from 1991 to 2020. This method is also used for presenting the characterization of land use change processes as balanced, quasi-balanced, imbalanced, extremely imbalanced status; one-way transition, two-way transition directions; negative and positive change trends. The results are showing that land use has changed with water body land use type in a drastically decreasing state over the past 30 years. The land use conversion has happened from open, green, and water body land use types to built-up land use types. These changes result in losses of one type of land use and gains in other types of land use. These events have presented fragmentation in patterns.

The changes, trends, and status present a quasi-balanced and two-way transition and positive change with built-up land use increasing and water bodies and other land use types decreasing. These changes in built-up and water bodies are majorly due to human activities such as construction, and haphazard development. Built-up land use type is the largest land use type which is having higher risks to surface water land use type. Vegetation land type needs to increase in the area so that water pollution and other negative phenomena can be reduced. These points on land use changes and changes in trends help to improve the decisions to formulate land development and management strategies.

Changes in landscape patterns have not been analyzed due to the lack of availability of accurate data and time shortage. This high spatial accuracy data shows the limitations of any developing countries' cities where urban growth is very haphazard and unplanned and previous data are not available. These tools are applicable anywhere in India for identifying changes in land uses, status, trends, and directions. By using these tools, land use management systems can be enhanced for protecting surface water resources in water-stressed areas. For further research work, this study has wide scope for investigating landscape pattern variations for protecting urban surface water resources.

This study also helps in the improvement of practices, policies, and plans related to surface water resources planning and land use development planning. Long-term solutions-based analysis needs to be conducted due to the lack of an appropriate database. Future research scope should focus on the quantification of changes in water quality, quantity, hydrological, morphological, and ecological parameters datasets.

Author Contributions: The conceptualization of the article is framed by R.B. and further developed by S.S. under the supervision of R.B. The methodology is comprehended by S.S. and formal analysis using software such as Arch GIS, Remote sensing, MS Excel for cross tabulation metrics is completed by S.S. Further the validation is done by R.B. and S.S. and investigation of the research objectives is by S.S. Resources and data curation are done by S.S. further writing-original draft preparation by

S.S. writing-review and editing are by R.B. and S.S. The visualization part is done by S.S. All authors have read and agreed to the published version of the manuscript.

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