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Impact of Urbanization on Groundwater Level in Kanpur City, Uttar Pradesh

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Abstract

Rural-urban migration is a major cause of water stress in cities. People move to cities in search of better opportunities, but this puts a strain on the already limited water resources. Climate change and urbanization are also contributing to the problem. Variations in the rate of urbanization are directly correlated with changes in groundwater levels. Urbanization is often accompanied by an increase in impervious surfaces, which can alter long-term water availability. Urban land predominates in this region. This study aims to determine the depletion of groundwater for the years 1995 and 2020 due to Land use and Land cover (LULC). Results of the study highlighted that urban growth expanded at an average rate of 2.97 km^2/year and depletion of groundwater in the study area was at 0.67 meters below ground level per year (mgbl/year). This study provides a general overview of the groundwater level change that may have an impact on the accessibility of potable water. Moreover, this study provides some valuable outcomes related to the management of groundwater and unplanned urban expansion of the city.

Keywords

Groundwater, Groundwater level, Land use Land cover, Satellite image, Urbanization

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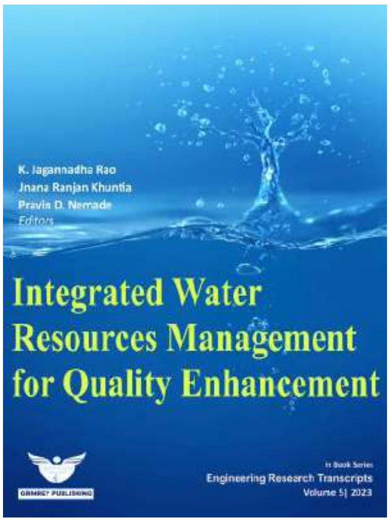

1. Introduction

Urban populations in developing nations depend heavily on groundwater for their overall economic and social well-being [1]. More than 50% of the world's population lives in cities, and it is projected that this percentage will rise over time [2]. Urbanization has been encouraged by significant labor migrants in search of new possibilities, students living in nearby rural areas looking for higher education, and a rapidly expanding tourism industry [3]. The people migrating from rural to urban are a result of urbanization. This is linked to the cutting down of trees, destruction of vegetation and forest land, and conversion of these places to modern infrastructure such as residences, road networks, industries, etc. [4]. Unsustainable planning and management as a result of global trends toward faster urbanization have severely degraded the ecosystem, particularly the plant cover and water supplies [5]. Due to an increase in the proportion of impermeable areas as a result of this procedure, groundwater recharge may be reduced. Urban water scarcity is recognized as one of the world's most serious challenges.

Groundwater is water that is found below the Earth's surface in the saturated zone, where the pore spaces in the soil or rock are filled with water [6]. The majority of the people that live in our country depend on this resource for their basic water needs [7]. To improve water resources and manage them scientifically, which is necessary due to the rising demand for water for domestic, industrial, and agricultural purposes [8] [9]. To manage aquifer systems effectively, groundwater resources must be continuously monitored [10]. The hydrologic cycle is significantly affected by changes in land use.

To understand the relationship between people and the environment, land cover change is a reliable parameter. Land use and land cover (LULC) are often used interchangeably, but they have different meanings. Land use refers to the way land is used by humans, while land cover refers to the physical features of the Earth's surface, such as soil, water bodies, vegetation, and other features. [11]. LULC patterns of the catchment have an impact on hydrologic processes [12]. Geographic information systems (GIS) and remote sensing approaches are effective tools for monitoring, mapping, managing natural resources, and evaluating land use dynamics in a given area [13]. Remote sensing and GIS are very capable tools for the study of LULC changes but studies based solely on these two may not be very suitable for given applications at the local level. Remote sensing can be used to classify images by taking advantage of the different types of information that can be obtained from different sensors [14].

Many factors have been discovered which contribute to the variation in LULC, including population increase, socio-economic changes, climate changes, poor planning, and implementation. Analysis of changes in LULC has become a crucial component that helps decision-makers to maintain sustainable development and comprehend the dynamics of changing environment [15]. Most parts of the world are currently experiencing widespread changes in LULC. These changes are driven by a number of factors, including rapid population growth, industrial development, and economic growth [4]. Increasing population in certain areas leads to the expansion of built-up land and the shrinking of forest land. On the other hand, areas of environmentally important LULC classes such as grazing land and forests have shrunk too much with time due to increasing cultivation and settlement in the same period.

Change in LULC is a significant factor that contributes to change in the environment. Satellite images have shown the temporal and spatial variation of LULC [16]. Defining, monitoring, and analyzing the geographical and temporal variations of LULC is extremely important so that we can better understand the land surface processes of the earth [15]. However, it is crucial to identify, track, and analyze the regional and temporal fluctuations in LULC. Various studies have investigated how changes in land use affect water resources and groundwater levels [4]. Sustainable land use planning and management, along with their proper implementation, can help conserve forest, soil, and water resources. Local communities can also be provided with alternative livelihood options to help undo undesired consequences of land use change [17].

A study found that changes in LULC due to urbanization in Bangui city from 1986 to 2017 resulted in an increase in the surface temperature [18]. Variations in LULC have a huge impact on the environment as well as society and it not only affects local but global systems as well by disturbing the balance of water, energy, and greenhouse gasses in the atmosphere [19]. The impact of urbanization on groundwater availability can be analyzed using LULC change data and groundwater data collected in situ [20] [21]. The rapid urbanization of any area promotes the demand for water for industrial, domestic, commercial, and other activities. Groundwater is a significant contributor to the demand for water in any area. The objective of this study is to compare the groundwater depletion between specific years (i.e. 1995 and 2020) due to LULC. For the execution of this work, remote sensing data and groundwater well data were used. Based on the results of this study, city administration can take some important decisions to control the rapid decline in groundwater and illicit expansion of urban areas.

2. Material and methods

2.1 Study area

Kanpur is the largest urban region in Uttar Pradesh and the eleventh most populated city in India. Kanpur city covers a total area of 260 km^2 and is located between latitudes 26°19′ and 26°33′ North and 80°12′ and 80°29′ East [22]. Additionally, it is arbitrarily divided into ll0 wards and 6 zones. It serves as the primary hub of industrial and commercial activity. Leather, wool, cotton, vegetable oil mills, chemical plants, and sugar refineries are all well-known in Kanpur. It is also known as the Manchester of the country. The city is bounded on its north and south by the rivers Ganga and Pandu, respectively [23]. The study area of Kanpur Nagar is shown in Fig. 1 using ArcGIS.

2.2 Data acquisition

In this study groundwater level and satellite-based remote sensors data were used. Groundwater level data was collected from Groundwater Department, Kanpur Division, Uttar Pradesh. Satellite-based remote sensors data, such as Landsat 5 Thematic Mapper (TM) imagery acquired in 1995 and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) imagery acquired in 2020, were obtained from the United States Geological Survey (USGS) Earth Explorer collection.

Landsat 5 was a satellite in the Landsat program launched by NASA in 1984 and was active until 2013. It carried the TM sensor, which had seven spectral bands. These bands covered a range of wavelengths ranging from 0.45 to 2.35 μm in the electromagnetic spectrum. Landsat 8, launched by NASA in 2013, is part of the Landsat program and carries the OLI and TIRS sensors. These sensors together provide a total of 11 spectral bands, covering a wide range of wavelengths ranging from 0.43 to 12.51 μm in the electromagnetic spectrum, allowing for various remote sensing applications, including LULC. In summary, Landsat 5's historical data is valuable for long-term studies, while Landsat 8's enhanced sensor capabilities and continuous data availability make it a preferred choice for current LULC mapping applications.

2.3 Preparation of LULC

Remotely sensed data from aircraft or satellites are typically subject to geometric distortions due to the motion of the acquisition equipment and platform. ArcGIS 10.8 was utilized to import the satellite data and perform rectification and classification. Further steps are followed as geo-referencing, mosaicking, and sub-setting the photos according to Area of Interest. To analyze all satellite data, each pixel has a specific value corresponding to a classification, a signature file was created, and the land area was divided into five classes based on the particular digital number values of various landscape aspects. Urban land, Cropland, Forest, Water, and Barren area were the distinct categories. To differentiate one class from the others, each was given a distinct identity and a certain color. Training samples were chosen for each of the predefined land cover/use types by defining polygons around typical locations [6]. The pixels within these polygons were used to capture the spectral signatures for the relevant land cover classes. A good spectral signature ensures there is a minimum misunderstanding among the land covers that needed to be mapped [24]. The Maximum Likelihood classification algorithm; one of the most popular as well as most commonly used image classification approaches was used for supervised image classification [25]. Based on the training sample, Maximum Likelihood Supervised Classification was done to create the 1995 and 2020 LULC maps [26]. Fig. 2 shows the stepwise methodology of LULC. This process was used to determine whether heavily populated areas had a stronger impact on LULC changes that affected groundwater levels.

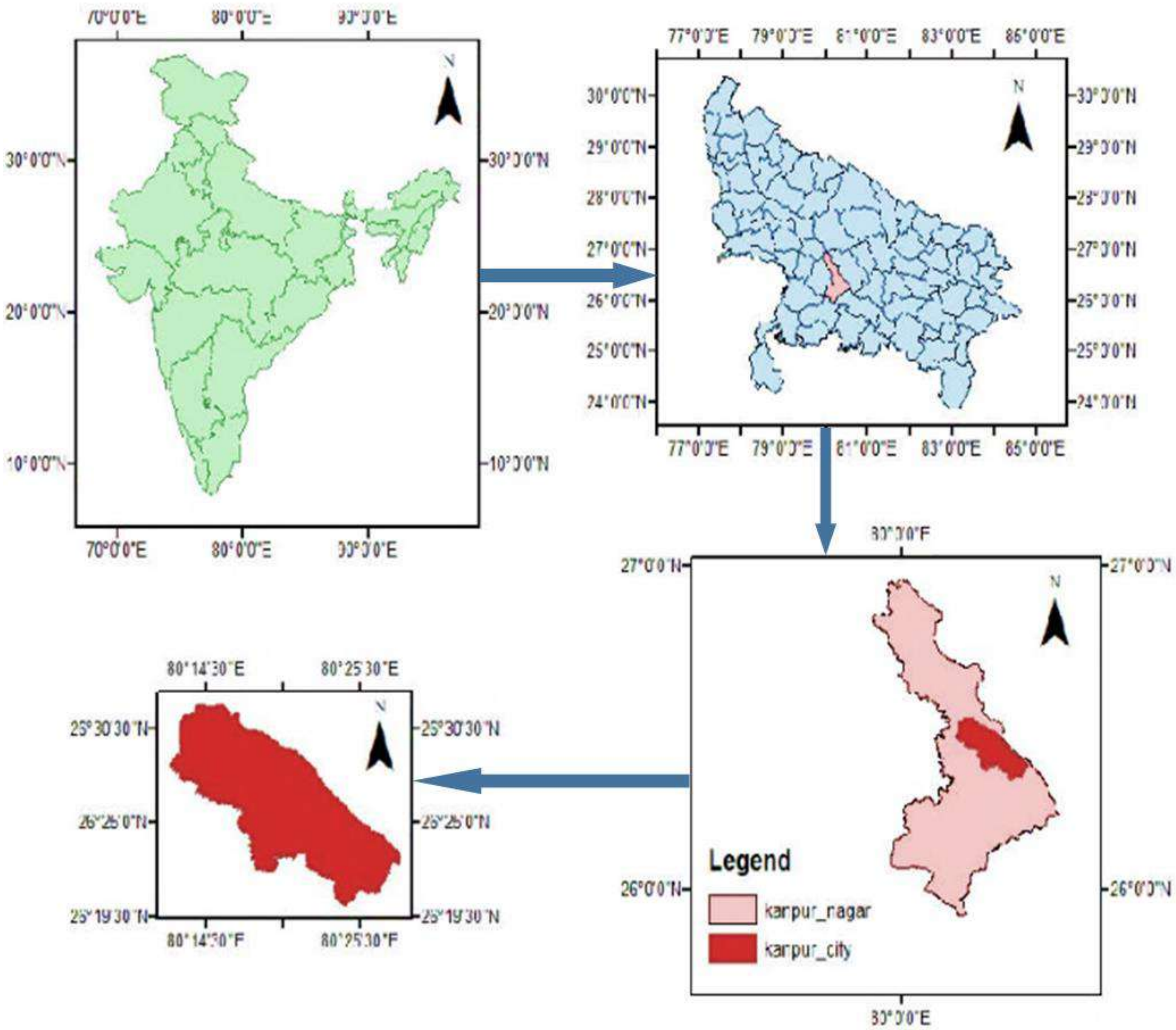

Fig. 1. Geographical location of Kanpur City

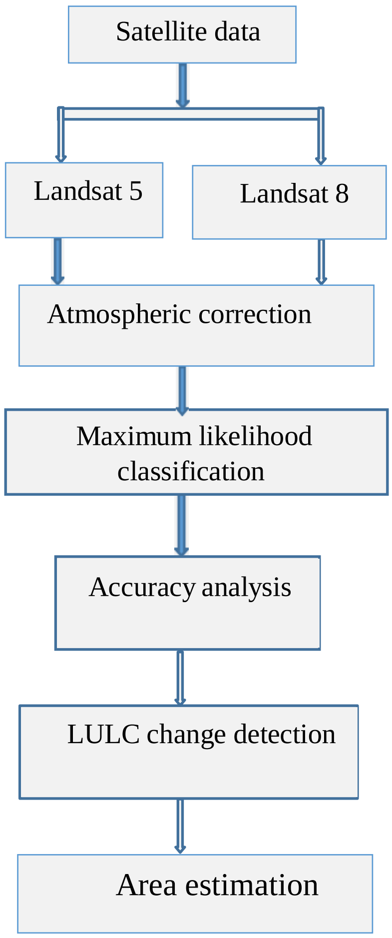

Fig. 2. The flowchart shows the overall methodology

3. Results and Discussions

Systematic urban growth can have both positive and negative consequences for natural resources and human life. However, unplanned urban growth always has a negative impact on the ecosystem. The process of conversion of a natural landscape to an urban region is irreversible, therefore the land has significantly and irreversibly altered from its initial state. Further, an increase in urban land development affects habitats and the depletion of water resources as well. LULC maps for the two years 1995 and 2020 were divided into five categories, i.e. water, forest, cropland, barren land, and urban land. Visual representations of LULC are shown in Fig. 3 and Fig. 5 for the years 1995 and 2020 respectively. Built-up areas experienced the most significant increase, with their share of land use increasing from 44.68% in 1995 to 73.20% in 2020.

Based on Fig. 4 and Fig. 6, it has been estimated that urban land increased by 0.64 times from 1995-2020. In the same manner, it can be written that water resources were depleted by 1.71 times in the seen period. A continuous decline was observed from variations in groundwater levels to unsustainable extraction of water. Groundwater levels decreased by 9.83 to 26.64 mbgl in the year 1995 and 2020 respectively. The average groundwater level declined at the rate of 0.67 mbgl/year.

It is interesting to observe that urban land use and cover from the year 1995 to 2020 decreased the percentage of barren land from 25.08% to 16.90%. Hence, the development of urban areas has led to the acquisition of barren land. On the second hand, this development also reduced the forest cover, cropland, and area occupied by water bodies. This shows the negative aspect of urban expansion.

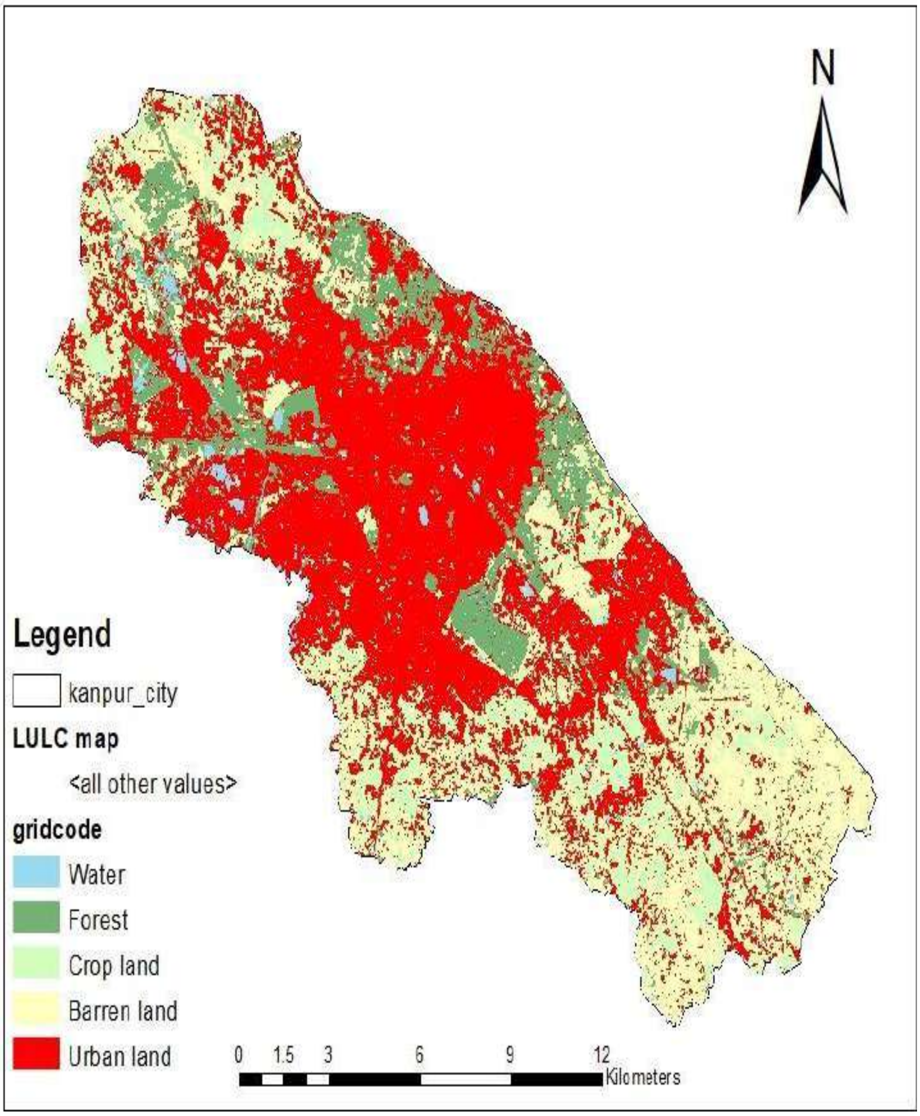

Fig. 3. LULC of Kanpur City, 1995

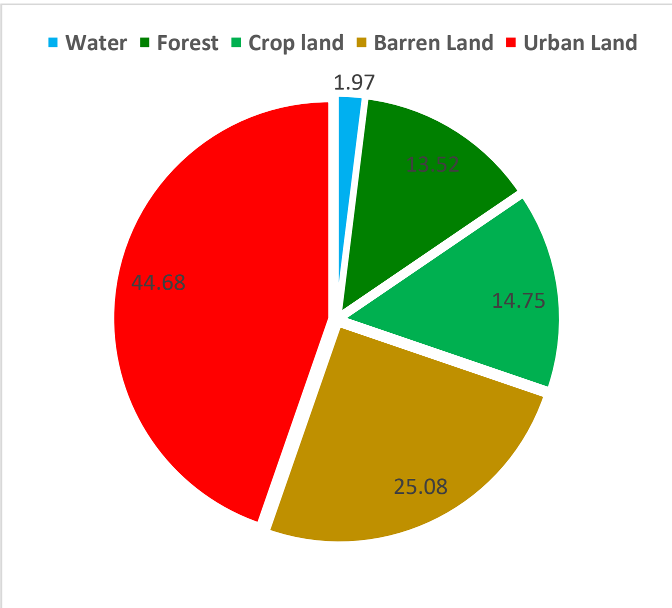

Fig. 4. Sector-wise LULC, 1995

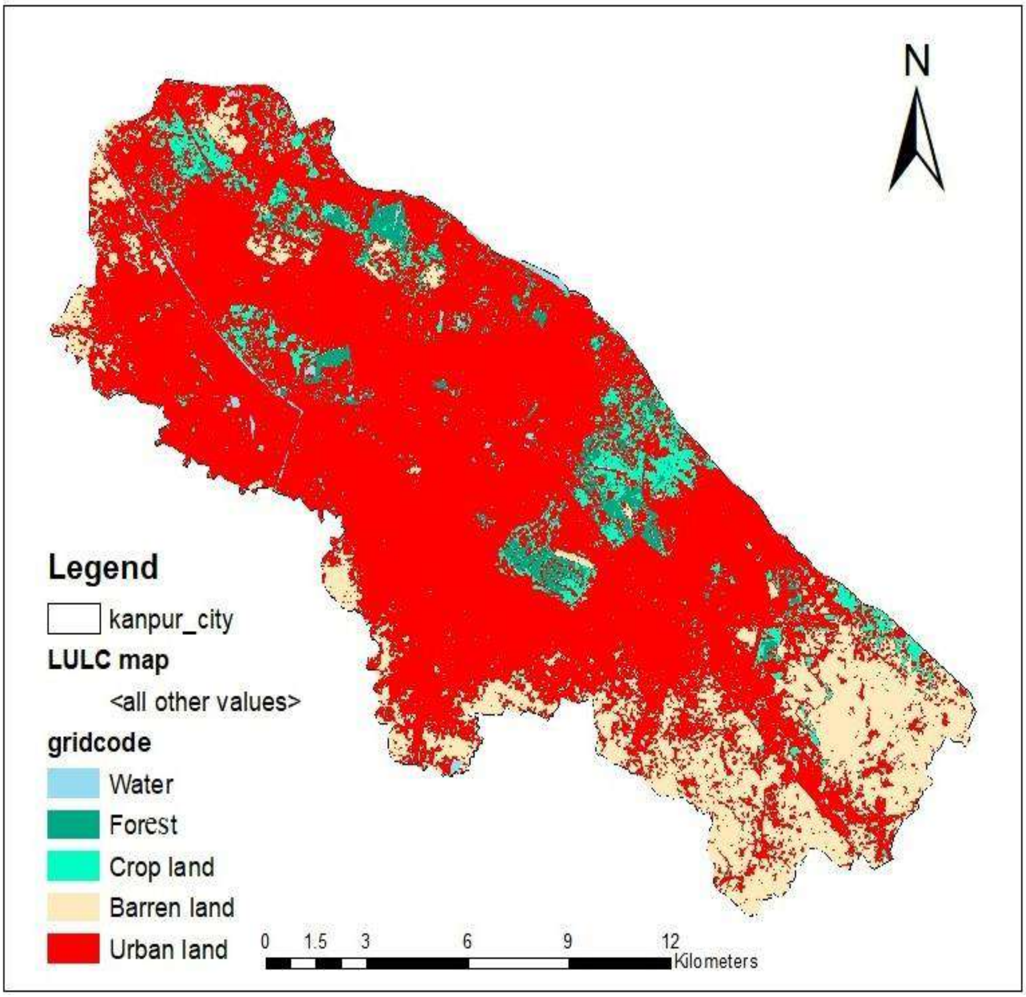

Fig. 5. LULC of Kanpur City, 2020

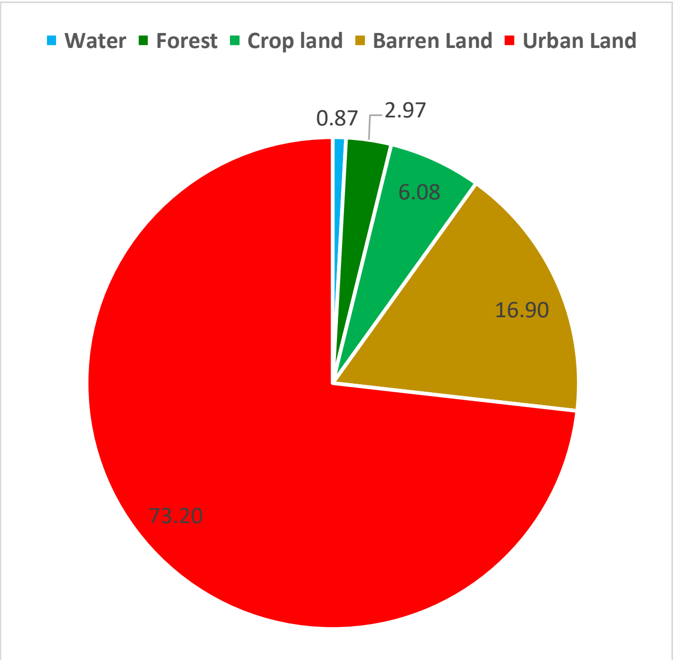

Fig. 6. Sector-wise LULC, 2020

4. Conclusions

Digital image processing techniques were used in the current work to evaluate LULC and detect their change. This study projects a significant change in LULC, which is expected in the area under study. According to the analysis, there was a significant decrease in water, forest, cropland, and barren land between 1995 and 2020 and an expansion of the urban area. Urban average growth is expanding at a rate of 2.97 km^2/year, while the groundwater level of Kanpur City is declining at an average rate of 0.67 mbgl/year. This shows an approximate 74.15 km^2 change in urban areas overall during the past 25 years (1995-2000). The change in groundwater level may affect the availability of freshwater resources. Based on the findings, it can be said that the expansion of urban land is one of the major causes of the lowering of the groundwater table. Moreover, a systematic planned urban expansion in barren land leads to a positive impact on the environment and society.

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