ANALYSING EFFECTS ON GROUND WATER LEVELS DUE TO CONVERSION OF RURAL TO URBAN LANDSCAPES

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ABSTRACT

Greater NOIDA evolved from 1991 with 101 villages to 2020 with 293 villages. This is an ideal case of rural to urban transformation in the immediate past. This transformation led to a decrease in recharging natural surfaces and an increase in impermeable surfaces. Along with the reduction in recharge areas, an increase in population has necessitated more and more extraction of groundwater resulting in an imbalance of water extraction and recharge. The result is depletion of groundwater levels in this area. The area is part of the wide Indo-Gangetic alluvium with sand, silt and clay layers resting on quartzite's of Delhi Super Group. Geomorphological map prepared using digital elevation models of the area shows older and younger alluvial plains and active flood plains of the river Hindan. Time series analysis of key land use land cover classes shows that recharge areas were reduced from 77 % to 30 % from 2005 to 2019 and impervious surfaces have increased from 19 % to 65 % for the same period. Aquifers of the area are both phreatic and semi-confined. The aquifer parameters estimated through step drawdown test and long duration aquifer performance test indicates that the average coefficient of transmissivity of the area is 1752 m^2/day and the average coefficient of storage is 4.84 x 10-4. Discharge of the wells shows a yield of 8 to 16 lps for a drawdown of 3 to 6 m. An attempt has been made to know the behaviour of groundwater levels during the same period as that of land use land cover. The results indicate a 74 % depletion in groundwater levels with an average annual depletion of 21 %. An interrelationship between urban growth and groundwater levels has been established in this study. This analysis indicates that as agriculture declined water levels also depleted and have a positive correlation of 0.852. On the contrary, as the built-up increased water level has depleted hence have a negative relationship with a correlation coefficient of -0.851. To make it a sustainable resource, these overexploited aquifers need careful participatory management by communities, Scientists, and policymakers.

Keywords: Groundwater, aquifer recharge, key land use classes, transmissivity, overexploited

INTRODUCTION

Water is an elixir for life. Mankind has evolved around this precious resource. As this life-sustaining resource was so abundant near human settlements, earlier he did not pay any special attention to this resource. Groundwater is the most reliable freshwater source which can be readily used for all purposes without much processing (Wandari *et al*., 2020; Cigna & Tapete, 2022). Moreover, groundwater is replenished annually through rainfall. As time has passed, the population has increased at an alarming rate, the quest for living space and infrastructure, turned villages into towns and big cities. The extraction of freshwater for domestic, commercial, industrial, and agriculture purposes expanded exponentially. Recharge areas of the earth become impermeable to water due to construction (Sahoo *et al*., 2021; Wang *et al*., 2010). This all leads to an imbalance between groundwater recharge and extraction rate resulting in depletion of the groundwater resource (Li *et al*., 2021; Naik *et al*., 2017).

The urbanization process has altered the quality and quantity of groundwater (Mishra *et al*., 2021; Xu, 1991). Almost 100 % of the drinking water requirements in urban areas are met with imported water supplies or Government controlled *in situ* water supplies. 50 % of the industrial water requirements are fulfilled by groundwater resources (Huang *et al*., 2022). As per the World Bank Statistics, 37 % of agricultural land in India are under irrigation and out of this 65 % of irrigation is done by using groundwater. 51 % of the food crops are produced using groundwater as irrigation means (Zhao *et al*., 2019). Urbanization has resulted in contamination of groundwater resources by industrial effluents, sewage water and by over usage of fertilizers and pesticides in the urban peripherals (Hudak, 1998; Romero *et al*., 2020).

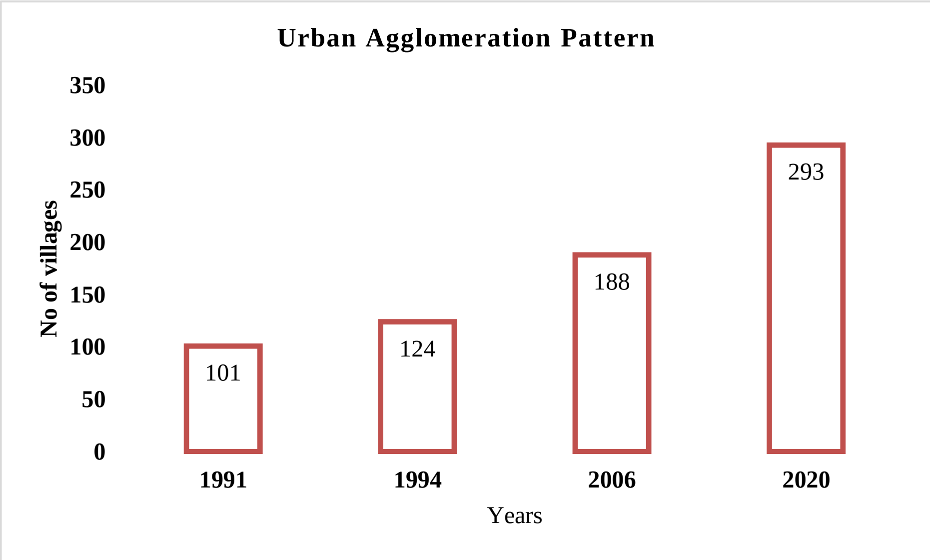
Generally, groundwater is viewed through the lens of a supply sided source. In factual terms, it is a resource. Here lies the importance of its management. Groundwater needs to be managed scientifically (An *et al*., 2016; Krisanti & Triningsih, 2020). Groundwater is not all about water extraction structures say wells, it is about aquifers where groundwater lies, moves and is stored. If storage is depleting, it needs to be refilled with participatory groundwater management. Community, scientists, and policymakers are its contributors.

The Greater Noida area is classed as overexploited from a groundwater point of view. Well planned strategies are required to conserve and augment groundwater resources (Saleem *et al*., 2020). This will lead to having an equal pace of water conservation and infrastructure development (Chhapariya *et al*., 2021; Garg *et al*., 2022). Major institutional policy and technological initiatives are enquired to ensure efficient socially equitable and environmentally sustainable management of our water resources (Upadhyay *et al*., 2011). Development of water resources must be to an extent such that it ensures the sustainability of the resources, both for the present and future generations (Peña-Arancibia *et al*., 2021; Sharma, 2009).

It is anticipated that global urbanization will bring 83 % of developed countries and 53 % of developing countries' population to its cities by 2030 (Ezzine *et al*., 2014; Zhou *et al*., 2021). Because of this coupled with irrigation through groundwater, world groundwater recharge-discharge balance is shrinking every day. Three major issues faced by the world's groundwater regimes are overexploitation, waterlogging and salinity and groundwater pollution (Chaudhary & Pandey, 2020; Mohammad *et al*., 2019).

Groundwater is a critical issue for cities around the world. The core of the issue is an abnormal increase in population. The need of the hour is integrated development of water resources and conservation of available water resources. Community initiatives to manage the water resources sustainably at local levels are most required (Chatterjee *et al*., 2009; Roy *et al*., 2020). In the present scenario, surface water resources are fully contaminated and there is immense pressure on groundwater reservoirs throughout India.

Fig. 1: Trends of expansion pattern in Greater Noida



The land use land cover changes are the major indicator for environmental changes in an urban area (Mishra *et al*., 2019; Pal & Shit, 2017; Vanama *et al*., 2019). As urban area expands, there will be a toll on natural resources. Water resources are especially sensitive to urban sprawl due to corresponding increases in population, reduction in recharge areas (Bauer *et al*., 2008; Farswan *et al*., 2019). Surface water sources are getting polluted, and groundwater will be over-extracted without any consideration to its safe yield resulting in depletion of water resources in terms of both quality and quantity.

Expansion of urban areas is at the cost of cultivated land (Ghawana *et al*., 2020; Shi *et al*., 2021). Losing cultivable land will lead to a reduction in recharge areas of water resources. More and more rural recharge areas of groundwater were turned into impervious urban surfaces. Fig. 1 shows the number of villages brought under the urban agglomeration during the expansion of Greater Noida. This indicates that more and more rural hubs joined in the making of present-day Greater Noida City. The broad objective of the study includes (a) temporal analysis of urban growth in the Greater Noida area, and (b) analyzing the behaviour of groundwater levels due to infrastructure development. The work includes time series analysis of land use the land cover of Greater Noida from 2005 to 2019, time series analysis of groundwater levels between 2005 to 2019 and establishes the relationship between specific land use classes about urban growth.

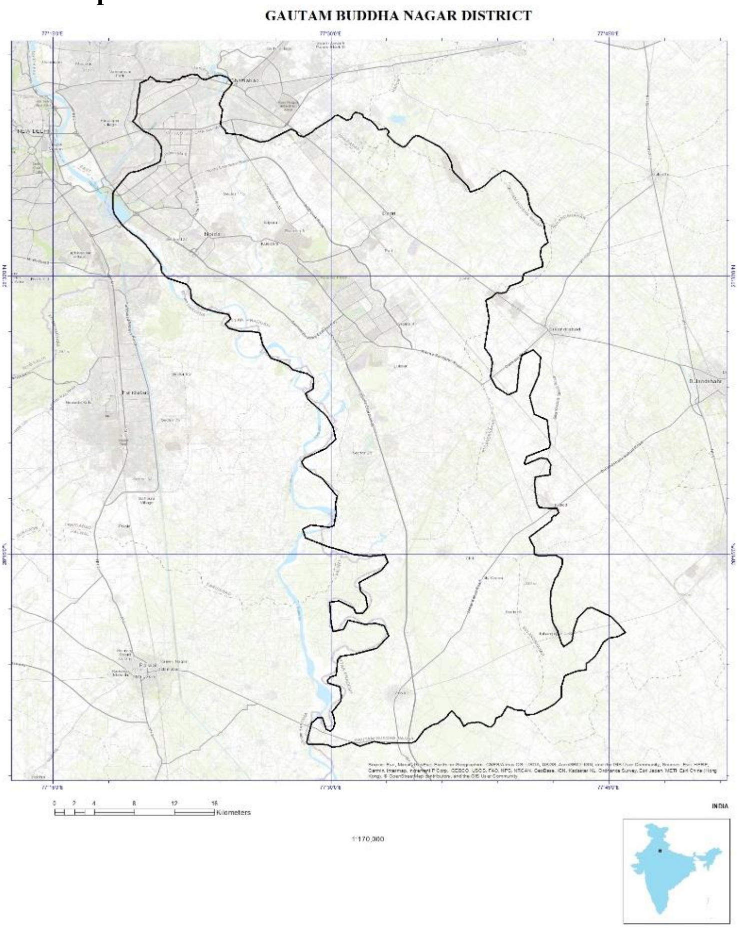
MATERIALS AND METHODS

Study area

Greater Noida is an integrated township set up in 1991 under the Uttar Pradesh Industrial Area Development Act 1976. This industrial area is the intersection point of Western and Eastern Dedicated Freight Corridors and is a gateway to Delhi Mumbai Industrial Corridor

(DMIC). It is part of the National Capital Region (NRC). It is the largest industrial township in Asia. The aim of developing this city is to provide a basic enabling framework for developing an efficient and integrated modern city with high service and delivery standards. It is one of India's smartest cities and a modern urban development centre of attraction. This metro centre is developed for providing quality urban amenities to decongest Delhi. Administratively, Greater Noida is part of the Gautham Buddha Nagar district of the State of Uttar Pradesh (Somvanshi & Kumari, 2020). The area is formed by agglomeration of about 124 of the easts while villages of the region have an area of about 38,000 ha. It is bordered in the North by Ghaziabad city, West by Noida city, East by GT Road and Northern Railway mainline to Kolkata (Follmann *et al.*, 2018; Saleem *et al.*, 2020). Greater Noida lies on the Eastern bank of the River Hindon. River Hindon is separating Greater Noida from Noida city. Geographically it is bounded by North latitudes of 28^0 19' 43" and 28^0 39' 43" and East longitudes of 77^0 23' 36" and 77^0 41' 12". A location map is shown in Fig.2.1. Physiography of the terrain is gently sloping undulating plains. Slope ranges between 0.1 and 0.2 per cent. Generally, the slope is towards the Southwest. The highest elevation is 214 M above MSL and the lowest is 193 M above MSL.

Fig. 2: Location map of the area



Greater Noida is built by amalgamating many villages situated in the area. The transformation of a rural village to a world-class city has its toll on the exploitation of natural resources. Overexploitation of groundwater is one such problem faced by the authorities responsible to cater drinking water to the communities (Malagavelli *et al.*, 2022). Overexploitation leads to lowering of water table which is forcing authorities to go deeper and deeper in the quest for more water. This has been exacerbated by the illegal extraction of groundwater by construction companies in the area (Khadse, 2021). As per Central Groundwater Authority (CGWA), Greater Noida has surpassed the level of critical and reached the level of overexploited.

Almost 100 % of the water demands of Greater Noida is fulfilled from groundwater resources. So, this resource needs to be managed democratically. So good governance and good management are necessary for the authorities responsible for water distribution to its communities. It is much easier to go for more and more bore wells and go deeper and deeper for water and build more tanks for distribution. But as a nation to ensure access to water is inadequate, equitable and sustainable way, we need to manage our precious resources carefully. Hindon River is an ecological resource of the area along with a few forest patches and some of the wetlands are the major ecologically sensitive area within the developmental area of Greater Noida. Some of the forest patches are also sensitive. The objective of developing this industrial city is to stop speculative land selling in this area, to provide job opportunities to the mass to decongest Delhi and develop as a recreational and knowledge centre of the country.

Climate condition

The study area falls under tropical climatic conditions with high temperatures and humidity. Scorching summers and shivering winters are common in this kind of climate. The onset of winters starts from the middle of October to February and summer starts from March to the middle of June followed by the rainy season up to the middle of October. The overall climate of the area is given in Fig.3. The details of the climatic parameters are given in Table 1.

Table 1: Climatic parameters of Greater Noida city

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Temperature (°C)	14	17	22.8	29	33.3	34	31	30	29	26	20	16
Min. Temperature (°C)	7.6	10	15.2	21	26.1	28	27	26	25	19	12	8.1
Max. Temperature (°C)	21	24	30.4	37	40.6	40	35	33	34	33	29	23
Precipitation (mm)	22	8	15	3	6	34	212	247	146	43	5	8
Total sunshine (hours)	240	250	260	280	300	220	200	195	225	280	275	260
Relative humidity (%)	58	52	38	28	29	45	68	70	62	43	40	58
No of rainy days	2.4	4	3.9	4.3	6.5	12	23	24	12	2.3	0.8	1.3
Wind velocity (m/s)	1.6	1.6	2.4	2.4	2.4	3.2	1.6	1.6	1.6	0.8	0.8	1.6

The measured precipitation is major rainfall in mm. The average monthly rainfall is shown in Figure 3. Fig 3 shows that the Greater Noida area receives an annual rainfall of 749 mm with minimum rainfall months being April, May, November, and December.

Fig. 3: Average monthly rainfall of Greater Noida

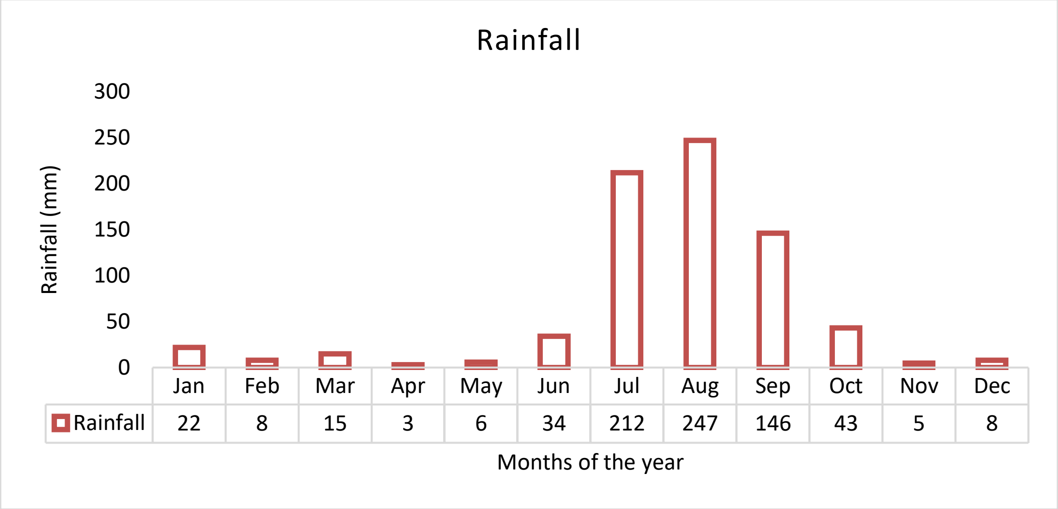
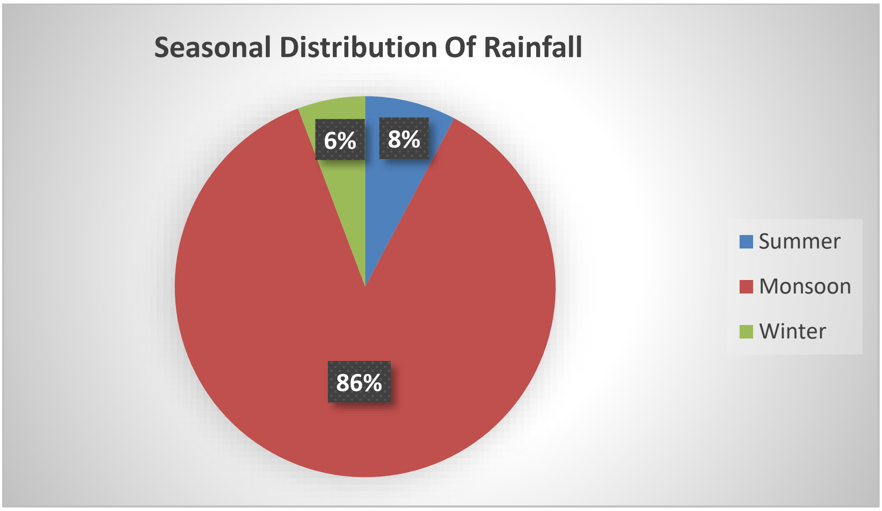


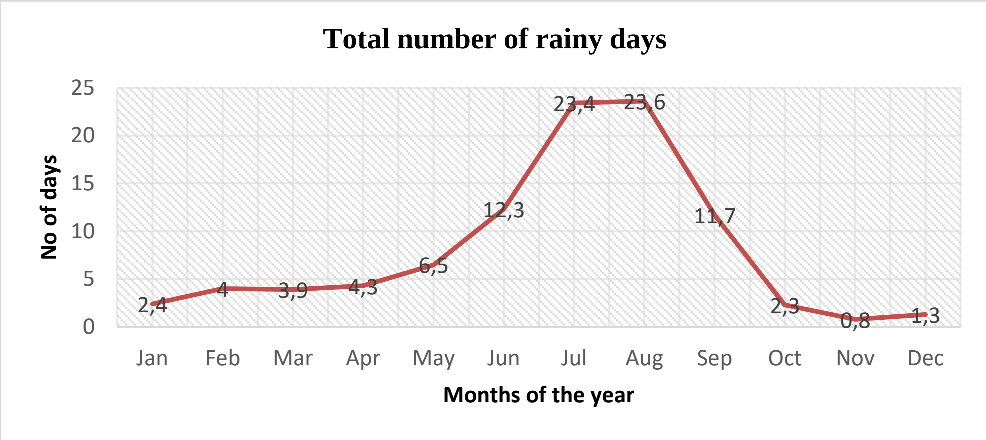
Fig. 4 shows the seasonal variations in rainfall. About 86 per cent of the rainfall is happening during the monsoon season with scanty rainfalls in summer with 8 per cent and winter with 6 per cent. This shows that there is a possibility of inundation along with the low-lying areas during the monsoon season and a high scarcity of water during other periods of the year.

Fig. 4: Seasonal distribution of rainfall



An analysis of several rainy days is shown in Fig 5. The total hours of rainfall in a month are converted to several days so that an actual number of wet days in a month can be ascertained. From this July-August months are mostly rainy months and followed by June and September with more than 10 days of rainfall and rest of the months in the year is with scanty rainy days. This forms pivotal information when planning for various rainwater harvesting structures.

Fig. 5: Month wise number of rainy days



Geological Setup

Geologically the area is part of the vast Indo Gangetic alluvial plains with unconsolidated deposits of Sand, silt, clay, gravel and kankar lying over Quartzite's of the Delhi Super group. Table 2 shows the geological succession of the area.

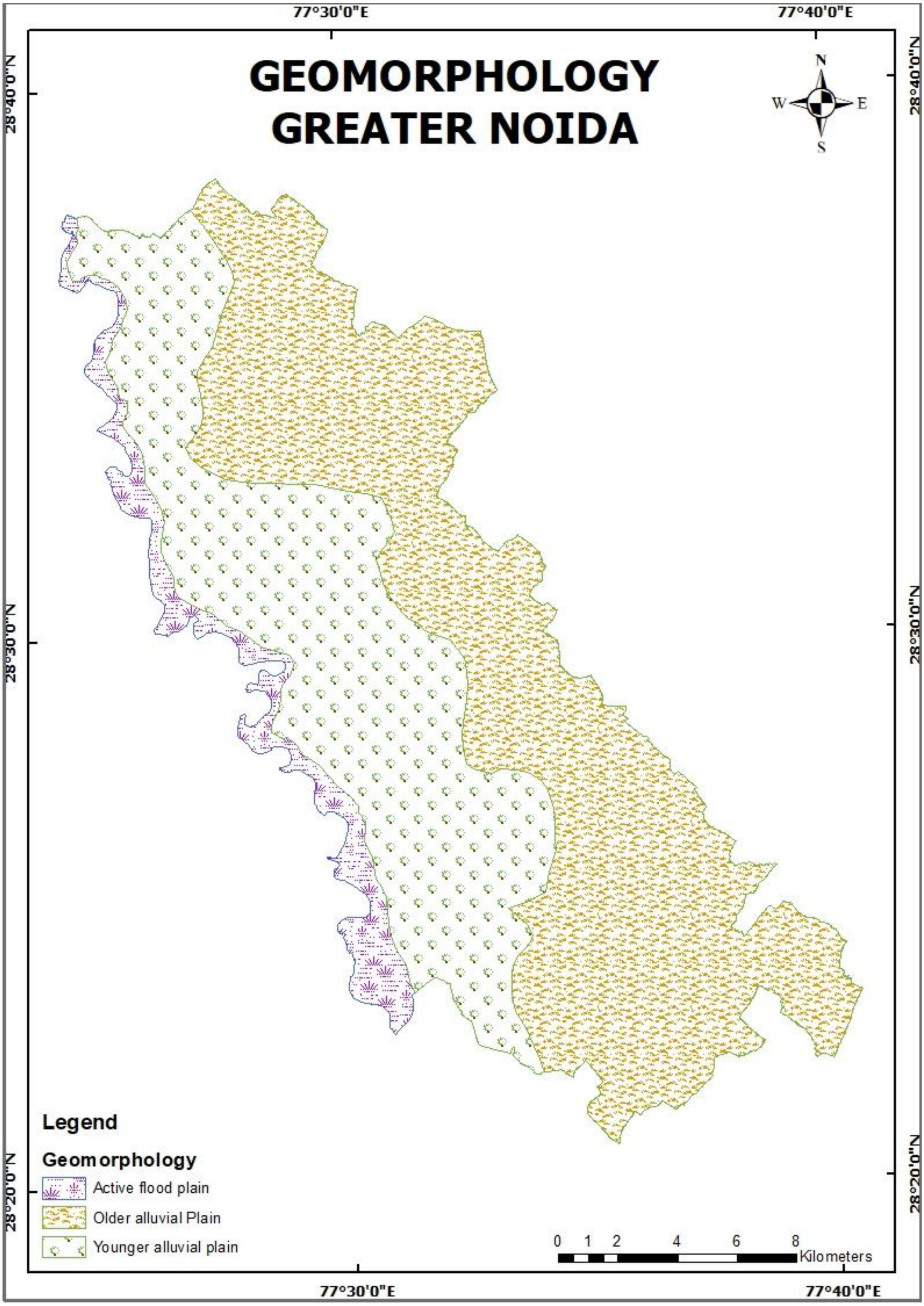
Table 2: Stratigraphy of Greater Noida area

Period	Age	Super Group	Group	Lithology
Pleistocene to recent	2.58 million years to 0.012 million years	Quaternary	Recent alluvium	Sand, silt, Clay, kankar, gravel etc.
			Older alluvium	Piedmont gravels, pebbles, cobbles, sand, gravel, clay and calcareous concretions
Unconformity				
Late Pre Cambrian	735 million years	Post Delhi	Intrusive	Quartz vein, pegmatites, granites, amphibolite
Archaean to Pre Cambrians	4.6 billion years	Delhi	Ajabgarh, Alwar	Quartzites, phyllites, mica schists, calc schists, gneisses, marble, basic flows, conglomerate, and other schists.

The alluvium and Delhi super groups and the Quaternary sediments are separated by a marked unconformity. The lithology of the wells made in these alluvial tracts shows deposits of sand, silt, and clay along with gravel and kankar. The collected lithology shows that in the Greater Noida part of the area basement rocks of Delhi super groups is not encountered in the drilling. This may be due to low drilling depths.

Geomorphology

Fig. 6: Geomorphological map of Greater Noida



Geomorphology controls the movement of water in an area. Geomorphologically, the study area is part of the Ganga-Yamuna flood plain with Hindon River as the Western boundary. It is a vast flood plain of the River Hindon dissected by its tributaries (Kumar & Bhaduri, 2018; Saleem *et al*., 2020). Geomorphologically the area can be divided into three main categories including (a) older alluvial plains, (b) older flood plains, and (c) active flood plains. As the area is part of interfluves of the River Hindan and River Ganga, older alluvium occupies a vast tract of the area. Ravines are common along active drainages as rivers flow through older soft alluvial plains (Khaled *et al*., 2020). These ravines are formed due to erosion of the older alluvial plains and give an undulating topography to the area. These are visible along Hindan, Lohiya Nadi, Bhuriya Nala area. Within the planes at places meandering scars can be interpreted from Satellite Images and SOI toposheets. These paleo channels are with coarse sand and are ideal for groundwater recharge. The elevation details and analysis of the Digital Elevation Model (DEM) shows that area is prone to unprecedented floods in the Hindan River as well as River Yamuna (Kumar & Bhaduri, 2018; Mittal *et al*., 2013). General Low topography is a big constraint in managing Stormwater in the city.

Soil conditions

As the study area is part of Indo-Gangetic alluvial plains, soils are composed of combinations of sand, silt, and clay. It ranges from pure sand to stiff clay (Mukherjee *et al*., 2017; Navale & Haldar, 2020). Pure Sand is called Bhur and clay is called Matiar. The fertility of the soil is depending upon the proportion of sand and clay. Pure clay exposures exhibit badland topography and sparse vegetation. Fresh alluvial soils and found along the Hindan River. At places, Kankars are also associated with clay. Kankar wherever it found forming small mounds. In general, topsoils are of high infiltration type (Jeong *et al*., 2019; Saleem *et al*., 2020). As the study area is part of the vast alluvial plain, its thickness is considerable.

Hydrogeology

The thick unconsolidated sediments of Indo Gangetic alluviums from the aquifers of the area. The thickness of the deposits is highly variable from a few meters to 400m bgl. These are very good repositories for groundwater. The granular zones are composed of sand, silt and gravel interlayers with clay deposits creating multiple layers of aquifers. These clay layers are the confining layers making deeper aquifers semi-confined to confine. Otherwise, groundwater in shallow aquifers is in phreatic conditions.

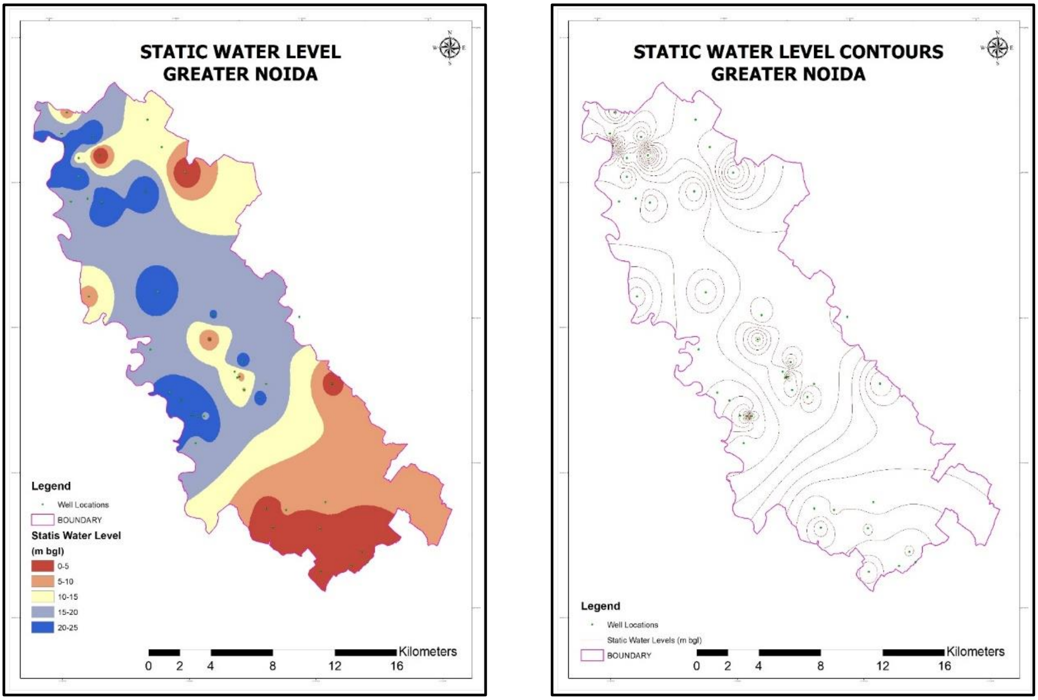
Phreatic aquifers are shallow and found to be a depth of 100 m bgl. Intermediate and deeper aquifers are going up to 400 m bgl which are confined or semi-confined in nature. The aquifer parameters estimated through step drawdown test and long duration aquifer performance test indicates that the average coefficient of transmissivity of the area is 1752 m^2/day and the average coefficient of storage is 4.84×10^{-4}. Discharge of the wells shows a yield of 8 to 16 lps for a drawdown of 3 to 6 m.

RESULTS AND DISCUSSIONS

Groundwater data analysis

Groundwater level data has been collected as primary data directly from the field. Water levels of 51 wells were collected through a field survey. The fieldwork was carried out pre-monsoon period of 2019. The well locations are distributed across the study area. The average water level of the area is 18.53 m bgl. The distribution of water levels across the area has been depicted in Fig. 7 and contour lines for the same is also shown in Fig. 7. The figure shows that in most of the areas of Greater Noida, the static water level is between 15 and 20 m bgl. The southern part of the area shows shallow water levels and the middle to northern portions shows deeper water levels (Lockhart *et al*., 2013).

Fig. 7: Static water levels across Greater Noida



The contour map shown in Fig 7 indicates that hydrostatic pressure is high in the northern portion of the study area. Whereas the rest of the area shows a very gentle pattern of contours which indicate low hydrostatic pressure on the ground waters of the area (Gesels *et al*., 2021).

Historic water level data has been collected from Central Groundwater Board (CGWB). Fig. 8 shows the temporal changes in the static water levels of the area.

Fig. 8: Historic water levels of Greater Noida

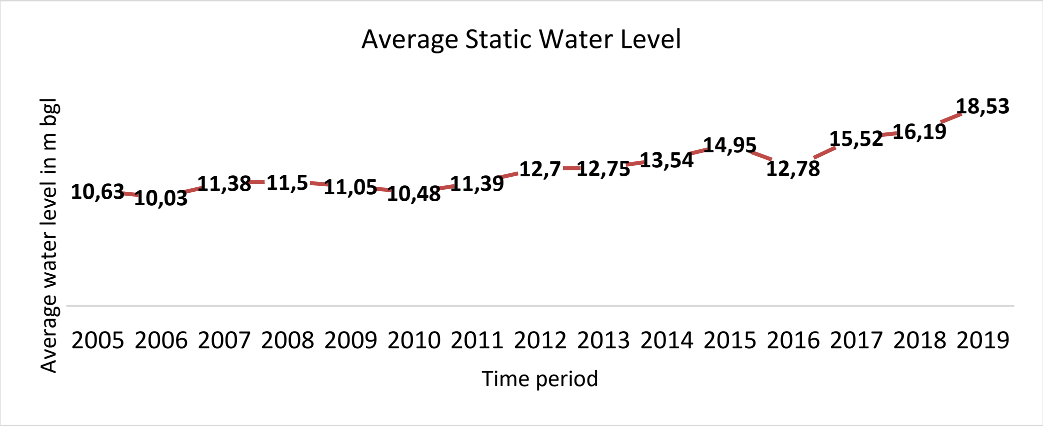
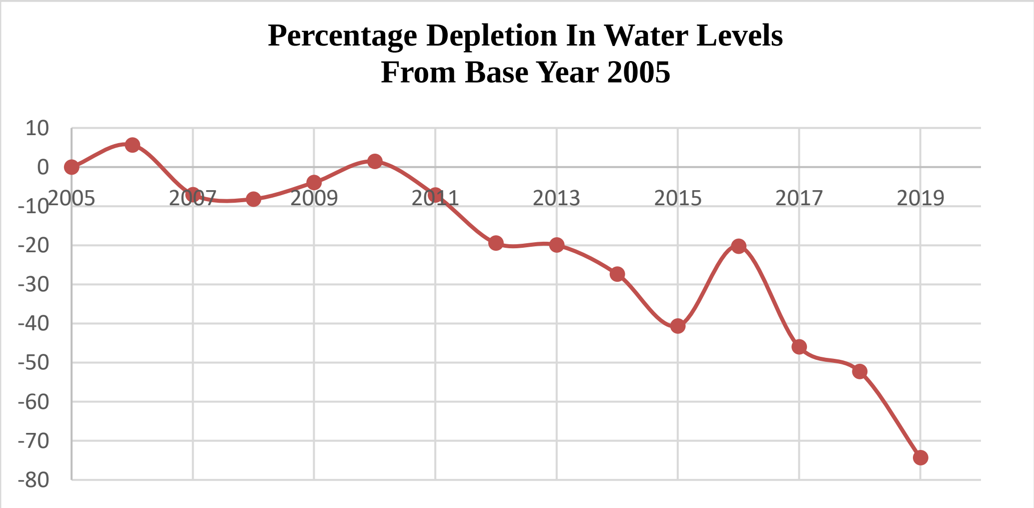


Fig. 9: Percentage lowering of groundwater levels with respect to base year 2005



The above figure shows that during 2005 the average water level of the area was 10.63 m Below Ground Level (bgl) and subsequently the water levels went deeper and now the average water level is 18.53 M bgl. This indicates that within 15 years water levels has gone down to about 8m. This contributes to the urban expansion and its consequent population increase and more quest for groundwater (Cao *et al*., 2019; Meldrum & Mickovski, 2017). Considering 2005 as the base year water levels have gone down in a significant way. Towards 2020 water level has gone down to 74 % for the base year. The average decline in water level is 21 % during this period. This clearly shows that with the development of urban infrastructure, stress on water level was there in Greater Noida and the rate at which water level lowering is alarming pointing to the need for water sensitive urban development (Roy *et al*., 2020; Shafizadeh-Moghadam *et al*., 2021).

Land use land cover mapping

Land use land cover maps of the Greater Noida area has been prepared for the years 2005, 2015, 2019. Satellite images of various resolutions were used in the study as per availability. Historic data of 2005 and 2015 were prepared on a 1:50,000 scale with low-resolution images. The images of 2005 and 2015 were converted to the land use land cover features of the area by classification techniques and final maps are in the form of raster outputs. However, during 2019 very high-resolution images were available and land use land cover maps were prepared using on-screen interpretations followed by detailed ground verification.

Land use land cover data has been further analyzed for key land use land cover features classes. Agriculture, built up, forest, barren land and wetland were taken as the key land use land cover features of the area (Ahmad *et al*., 2021; Lockhart *et al*., 2013). Most of the subclasses were merged with these key land use land cover classes. For example, agricultural plantations and fallow land were merged with cropland to get a total area for agriculture. Similarly, all urban built-up classes were merged to get the built-up class. So is the case with forests and wetlands.

During 2005 the study area compasses about 77 % of agricultural land and 19 % built-up land. These were the major land use classes, and the remaining barren land, wetland and forest were with 1 to 2 % of the total area.

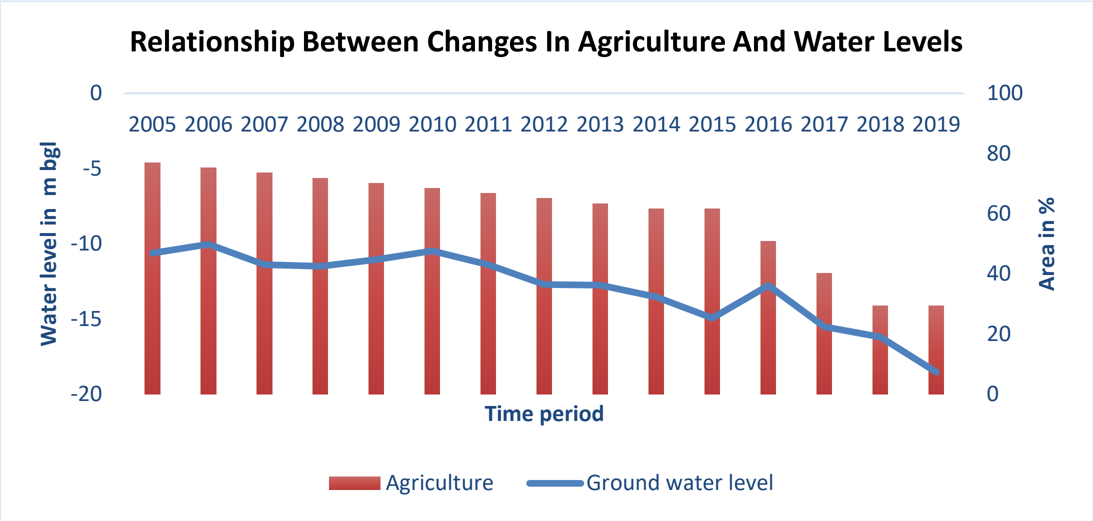
During 2015 the agricultural area reduced to 62 %. Built-up land increases to 33 % and forest, barren land, and wetland shows 0.73 %, 1.5 % and 3 % respectively. Most recent satellite images interpreted land use land cover details shows that agricultural land has shrunk to 30 % and built-up increased considerably to 65 %. Forest and wetland have 2.8 % of the total area while barren land remains with 0.03 %.

Impact of urbanization on groundwater levels

The above section clearly shows that bypassing year’s groundwater levels have been lowered considerably. In this research, an attempt has been made to evaluate the relationship between the land-use changes and the lowering of water levels. Land use statistics were worked out for the years 2005, 2015 and 2019. This data set has been worked in terms of percentage of total area. Out of the key land use classes for which area statistics were worked out, agriculture and built-up classes were selected for this analysis. Urban water management considers total water cycle to facilitate the integration of water factors during the land planning process. It is encouraged by all levels of government and industry to adopt water management and urban planning practices that benefit the community, the economy and the environment (Kaushik *et al*., 2004; Perkins, 2021). These includes all water in the urban environment considering the natural surface water and groundwater. These are delivered for potable use, sewage and other 'waste' waters,

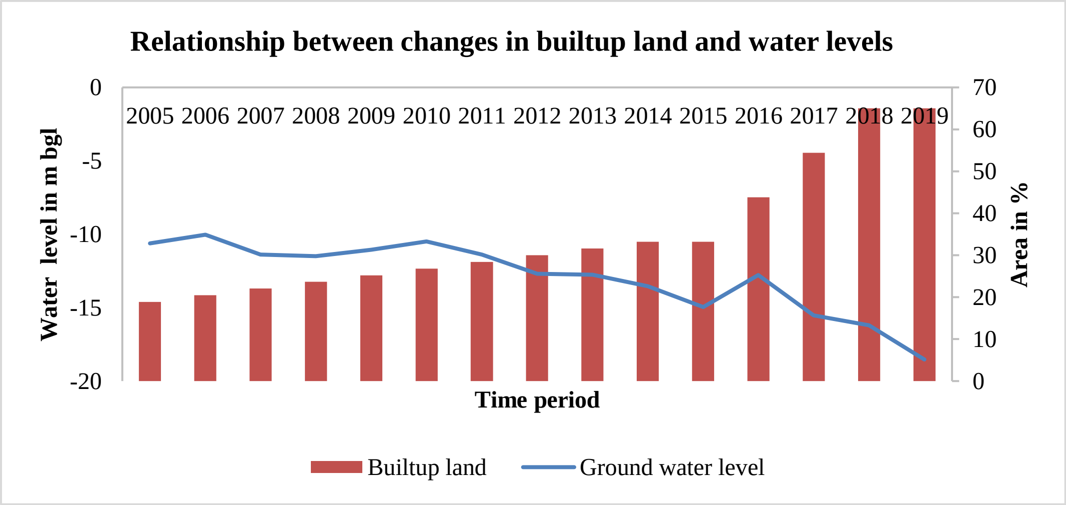
Groundwater levels were available from 2005 to 2019. But land-use information is available only for specific years of 2005, 2015 and 2019. So intervening year’s land-use situation is estimated taking the assumptions that land-use changes were linearly happened in between 2005 and 2015 and also in between 2015 and 2019. The data thus generated is given in table no.3 along with various statistics worked out of it.

Fig. 10: Changes in agriculture and groundwater levels from 2005 to 2019



Now continuous data is available for the variable groundwater level and land use classes. Rapid urbanisation has raised the concerns for competition for freshwater between cities and agriculture. Water scarcity in the rural to urban regions has become a common strategy to meet freshwater needs in growing cities (Angelidou *et al*., 2016; Saleem *et al*., 2020). The relationship between groundwater levels and extent of agriculture and groundwater levels and built-up land is depicted in Fig.10 and Fig.11 respectively. The land use classes are represented by the percentage of total area.

Fig. 11: Changes in built-up land and groundwater levels from 2005 to 2019



The above Figure shows the relationship between changes in agriculture and groundwater levels. Groundwater levels were shown meters below-ground levels and hence the values are depicted as negative numbers where the ground level is zero. That means as years go groundwater levels go deeper and deeper. The figure shows that agriculture is declining year after year and changes are more rapid from 2016 onwards. This shows the pace of urban development is more in recent years. Groundwater levels also show corresponding changes in tune with the changes in agriculture (Li *et al*., 2021; Malagavelli *et al*., 2022). It is also observed that with the decline of agricultural areas, groundwater levels show a lowering trend. Thus, these two parameters show a clear positive relationship that means, as agriculture decreases water levels also decreases (Perkins, 2021; Rostami *et al*., 2020).

Built-up land is showing uniform increase from 2005 and during 2015-16 it is showing a sharp increase (Agariga *et al*., 2021). This shows that urbanization is increased pace in the recent past. Groundwater levels are showing a corresponding decline. This shows as built-up land increases and groundwater level goes deeper (Pollicino *et al*., 2021). Thus, a negative relationship is observed between built-up land and groundwater levels. Figure 11 shows the relationship between the built-up land-use class and groundwater levels. The above table shows the statistics worked out between groundwater levels, agricultural land, and built-up land. Covariance between groundwater level and agriculture shows positive values and between groundwater level and built-up area is negative.

Table 3: Statistical analysis of groundwater levels and key land use classes

Year	**Groundwater Level**	**Agriculture**	**Built-up**
	M bgl	**% Of the total area**	
2005	-10.63	76.95	18.87
2006	-10.03	75.25	20.46
2007	-11.38	73.55	22.05
2008	-11.5	71.85	23.64
2009	-11.05	70.15	25.23
2010	-10.48	68.45	26.82
2011	-11.39	66.75	28.41
2012	-12.7	65.05	30
2013	-12.75	63.35	31.59
2014	-13.54	61.65	33.18
2015	-14.95	61.64	33.22
2016	-12.78	50.89	43.81
2017	-15.52	40.14	54.4
2018	-16.19	29.39	64.99
2019	-18.53	29.37	65
Average	-12.89	60.30	34.78
STD Deviation	2.44	15.71	15.28
Covariance		32.67	-31.72
Correlation coefficient		0.852	-0.851

The correlation coefficient worked out shows very good correlations between urban development and groundwater levels. Agriculture shows a positive correlation of 0.852 and built-up land shows a negative correlation of -0.851. The values near 1 show a very good correlation and both agricultural land use and built-up land have equal impact on groundwater (Agariga *et al*., 2021; Saha, 2017). This indicates that built-up land has been increased with a compromise on agricultural land. Either reduction in agricultural land or increase in built-up land has an equal impact on groundwater levels.

Groundwater is one of the major sources of water supply and for private domestic and industrial use in most of the urban areas. The subsurface water level has also come to serve as the receptor for added urban and industrial wastewater and for solid waste disposal (Chhajed-Picha & Narayanan, 2021; Powley *et al*., 2016). There are several prevalent signs of groundwater degradation caused by excessive exploitation and inadequate pollution control. The work also shows a detailed investigation of the mentioned urban area. The present paper can be an eye-opener for the interdependence of groundwater and urbanisation among urban policy-makers to provide a framework for systematic consideration of groundwater in urban management (Ahmad *et al*., 2021).

Water reallocation from rural to urban areas requires a global attention to demand of water due to increasing the trends of increasing urbanization, water supply transitions due to climate change, and over populations (L. Shi *et al*., 2021; Xie, Lark *et al*., 2019). Water reallocation projects are often expensive, time-consuming, and can have significant consequences to the environment. These decisions are ultimately political, and deserve to be underpinned by rigorous evidence to negotiate the trade-offs for all involved.

Water shortages and environmental issues is frequent in developing urban cities and towns. Urbanization leads to an increase in urban water demand and consumption; water shortages or crises, as well as degradation of the water environment, put the quality of urbanisation at risk. While cities face water shortages as a result of climate change and rapid population expansion, the effects of urban development patterns on future municipal water shortages are rarely studied. We examine the effects of sprawl vs. high-density patterns on future changes in the sub-annual water shortage intensity relationships to address this element of urbanisation. The water supply system has been chosen as an example of a rapidly developing region in recent decades. The Integrated Urban Water Model (IUWM) is used to forecast future water demand for both sprawl and high-density development patterns. In comparison to the high-density pattern, the demonstration research shows that metropolitan areas with a sprawl development pattern are more prone to encounter water scarcity episodes with greater intensity, duration, and frequency. Characterizing the effects of urban development patterns on future water shortage conditions is necessary for sustainable water management and smart urban growth, and can assist urban planners and water managers in developing an adaptive path to meet future water demand while reducing the vulnerability of municipal water supply systems to shortages. Water scarcity is a big worry in today's world. In many metropolitan places today, water scarcity is a big concern. Rapid urban population increase, combined with poor planning, pollution, poverty, and conflicting resource demands, all contribute to water stress, with urban water use expected to treble by 2025. Climate change is projected to have a considerable impact on precipitation patterns, affecting water supply and causing water-related calamities.

CONCLUSIONS AND SUGGESTIONS

This research study leads to the conclusion that groundwater is the most reliable freshwater source which can be used for all purposes without much processing. The reasons for groundwater level depletion are an imbalance between the rate of extraction and the rate of recharge. The Greater Noida area is classed as overexploited from a groundwater point of view. The reason behind this is urban expansion. As more and more villages converted to urban areas and impermeable built-up areas increased, shrinking of recharge areas took place and groundwater levels have gone deeper due to depletion. The average annual rainfall of the area is 749 mm. Geologically, the area is part of the vast Indo-Gangetic alluvial plains with unconsolidated deposits of sand, silt, clay, gravel and kankar overlying Quartzite's of the Delhi Super group. Hydrogeological the area is exhibiting both phreatic shallow aquifers as well as deep confined to semi-confined aquifers. The thickness of the alluvium in this part varies from 01 to 400 M. The aquifer parameters estimated through step drawdown test and long duration aquifer performance test indicates that the average coefficient of transmissivity of the area is 1752 M^2/Day and the average coefficient of storage is 4.84×10^{-4}. Discharge of the wells shows a yield of 8 to 16 lps for a drawdown of 3 to 6 M

Land use land cover of the area is mapped for 2005, 2015 and 2019. Agriculture, built up, barren land, wetland and forest land are taken as the key land use classes for the analysis purpose. Agriculture has reduced from 77 % to 62 % to 30 % from 2005, 2015 and 2019 respectively. Similarly built up has increased from 19 % to 33 % to 65 %. Barren land has been reduced and wetland and forest land have shown minor increases. The average groundwater level of the area is 18.53 M bgl. Groundwater level ranges from 15 to 20 M bgl. The southern part of the area shows shallow water levels and the middle to northern portions shows deeper water levels. Hydrostatic pressure is high in the northern portion of the study area. Time series analysis of the groundwater levels indicates that from 2005 to 2020 groundwater level has depleted to 74 % with an average decline of 21 % per year. An interrelationship between urban growth and groundwater levels has been established in this study. This analysis indicates that as agriculture declined water levels also depleted and have a positive correlation of 0.852. On the contrary, as the built-up increased water level has depleted hence have a negative relationship with a correlation coefficient of -0.851.

As the aquifers of the area were impacted with rural to urban transformation and its storage is depleting, it needs to be refilled with participatory groundwater management. Community, scientists, and policymakers are its participants. Infrastructure developments need to be water sensitive, and extraction needs to be compensated with water conservation measures such as rainwater harvesting and aquifer recharge. Major institutional frameworks, policy decisions and technological initiatives are required for the same. Development of water resources must be to an extent such that it ensures the sustainability of the resources, both for the present and future generations.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper

AUTHOR CONTRIBUTIONS

Mr Ashwani Kumar conceived and Dr Deepak Kumar designed the study, and Mr Ashwani Kumar performed the research, Dr Deepak Kumar analyzed the data, and contributed to editorial input. Dr. S.M. Veerabhadrappa performed language corrections.

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