A DISSERTATION
ON

GIS BASED VULNERABILITY MAPPING OF GROUND WATER USING DRASTIC MODEL IN DELHI REGION, INDIA

PROJECT REPORT SUBMITTED IN THE PARTIAL FULFILMENT OF AWARD

FOR

DEGREE OF

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

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under supervision of

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MAY 2023

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**GIS BASED VULNERABILITY MAPPING OF GROUND WATER USING DRASTIC MODEL IN DELHI REGION, INDIA**" which is submitted by Jigyasa Soni Roll No. 2k21/ENE/06, **Department of Environmental Engineering**, **Delhi Technological University**, Delhi in partial fulfilment of the requirement for the award of the degree of **Master of Technology**, is a record of the project work carried out by the student under my supervision.

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CANDIDATE'S DECLARATION

I, *Ms. Jigyasa Soni* student of M. Tech., hereby declare that the project titled "**GIS BASED VULNERABILITY MAPPING OF GROUND WATER IN DELHI REGION, INDIA**" which is submitted by us to the **Department of Environmental Engineering**, Delhi Technological University, Delhi in partial fulfilment of the requirement for award of degree of Master of Technology in Environmental Engineering, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi
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Place: Delhi
Date:

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SUMMARY

Freshwater resources amounts to only 31 % out of total water resources in which 1 % surface water has been exploited extensively. The ministerial and other report has been evidenced its exploitation. There is a continuous deterioration in the ground water quality along with the depletion of the levels of Ground Water. The epicentre of major interventions and setting severe pollution standards, have been picked up for this study in Delhi. Setting up a priority list are the precursor of Vulnerability mapping of any area which gives an information about its necessity to taken care of and taking actions before its gets into a irreversible and implacable scenario. An average ground water level of Delhi is varying from 2-65 mbgl. In the study for vulnerability mapping of Delhi, the DRASTIC Model of ARCGIS is used. DRASTIC model is a combination of Groundwater table depth, recharge rate, aquifer media, soil profile, topography, effects on the vadose zone, and hydraulic conductivity are some of the factors to consider. After running the model was mapped appropriately via considering the statistics available for the period 2019–20. The contour mapping shows that Delhi's south, west, and north eastern regions are the most vulnerable, possibly as a result of unlined drainage, rapid growth, and the presence of local dumpsites. Studying the flow of pollutants that leak into groundwater from waste sites enables the identification of major pollutant concentration locations. The idea of "digital transformations" could be used in the policies formulation of this issue. The report also discusses capacity building, policy interventions, and technological initiatives that could be used.

List of Abbreviations

NCT of Delhi	National Capital Territory of Delhi
LULC	Land Use Land Cover
CGWB	Central Ground Water Board
MoEF&CC	Ministry of Environment and Climate Change
CGWA	Central ground water Authority
DPCC	Delhi Pollution Control Committee

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Chapter 1 .

Introduction

Delhi region is moving from water stressed to water scarce (PIB,2017), there is a crucial parameter i.e. Ground water has to be analysed for the sake of capacity building and proper management of water. An area of 1437 km^2 in Delhi, with its annual rainfall averages 794 mm. About 4000 Billion cubic meter (BCM) per annum is the total water availability of India received through precipitation as per the National Commission on Integrated Water Resources Development (NCIWRD) report. 1869 BCM water is available as natural runoff after evaporation. 61% of surface water and 39% of replenishable ground water of total utilizable water availability is limited to 1123 BCM per annum because of geological and other factors. The different geological formations of Delhi, such as the Delhi Quartzite and the Older and Younger Alluvium, affect the availability of ground water. In general, the depth to water level in 2020–2021 ranges from less than 2 mbgl in parts of the North West and West district and the Yamuna Flood Plain to more than 65 mbgl, mostly in areas covered by Delhi Quartzite in the Central, New Delhi, and South districts. It is evident that there are dynamic changes in shallow water zones because of the significant seasonal variation in water level for depths up to 5 mbgl. According to the CGWB 2021–22 report, the GW level has decreased by 0–4 m in numerous areas of the state over the past ten years.(Ground Water Year Book, 2021).

In the years 2020–21, Delhi generated a total of 11108 Tons per day (TPD) of municipal solid waste. 52.5% (5828 TPD) of the Municipal Solid Waste generated in Delhi was dumped at the three dump sites at Ghazipur, Bhalaswa, and Okhla, while 47.5% (5280 TPD) was processed, treated, and disposed of through the city's three waste to energy and composting facilities (D.K.Singh, 2022). In addition to this, there are two proposed MSW processing plants in Ghonda and Ranikhera, as well as a 2000TPD engineered sanitary landfill at Tehkhand. Taking into account that the NCR Bandhwari landfill in Haryana is a massive landfill that threatens the Aravallis.

The groundwater in the NCR, which includes areas of Haryana, Rajasthan, and Uttar Pradesh, included contaminants such heavy metals. Electrical conductivity in Delhi's majority of districts is above the recommended level of 3000 micro mhos/cm, causing salt problems.

Nitrogen and fluoride levels are likewise excessive, at 45 and 1.5 mg/l, respectively (Machiwal et al., 2018).

According to Jiradech (2013), “groundwater vulnerability is defned as the tendency or likelihood of contaminants reaching the groundwater system after introduction at the surface and is based on the fundamental concept that some land areas are more vulnerable to groundwater contamination than others.” Under increasing threat in terms of quantity and quality due to population growth, climate change, agricultural and industrial expansion has been universal characteristic of groundwater system (Elshall AS. ,2020).

Ground water in Delhi is seriously threatened by un-engineered landfill sites. Leachate tends to move to the bottom of the aquifer when it drifts over the top of the liner, carrying the contaminant leached with it (S. K. Singh & Chawla, 2008). Leachate is transported in ground water by a number of different mechanisms, the first of which is advection transport caused by the mean flow of rivers or streams. Diffusive transport because of a concentration gradient comes in second. Dispersion, the third step, involves combining the pollutants. Fourth is sorption, the process by which one material binds to another (S. K. Singh & Chawla, 2008). The solute transport in streams for both surface and ground water may now be calculated using modern flow and solute transport modelling tools. USGS's MT3DMS model has been a popular one for this use. (2012) (C. Zheng et al.)

The objectives of this study are

1) To study the cause-and-effect relationship for ground water contamination in Delhi.
2) To Study the flow transport from dumpsites in Delhi using existing literature.
3) To map vulnerability of Ground water in Delhi using DRASTIC model method in GIS.
4) To prepare a sustainable water management program for Delhi for capacity building techniques (based on the vulnerability index) for ground water management.

This study has demonstrated Delhi's ground water's susceptibility in terms of both quantity and quality. The location of the largest pollutant concentrations can be determined by analysing the flow of contaminants from waste sites that seep into groundwater. With the help of the model, it may be possible to avoid contaminating both surface and ground water, which would otherwise combine with the Yamuna River. Suggestions for capacity-building are also provided in order to enhance Delhi's current ground water issues. The individual will be able to comprehend contributions at each level to enhance the circumstances and have a healthy environment with the assistance of capacity development measures, which include interventions in policies and technologies. The (fig1.1) geological map of Delhi illustrates the main types of soil found in and around the Yamuna river plain and in adjacent district.

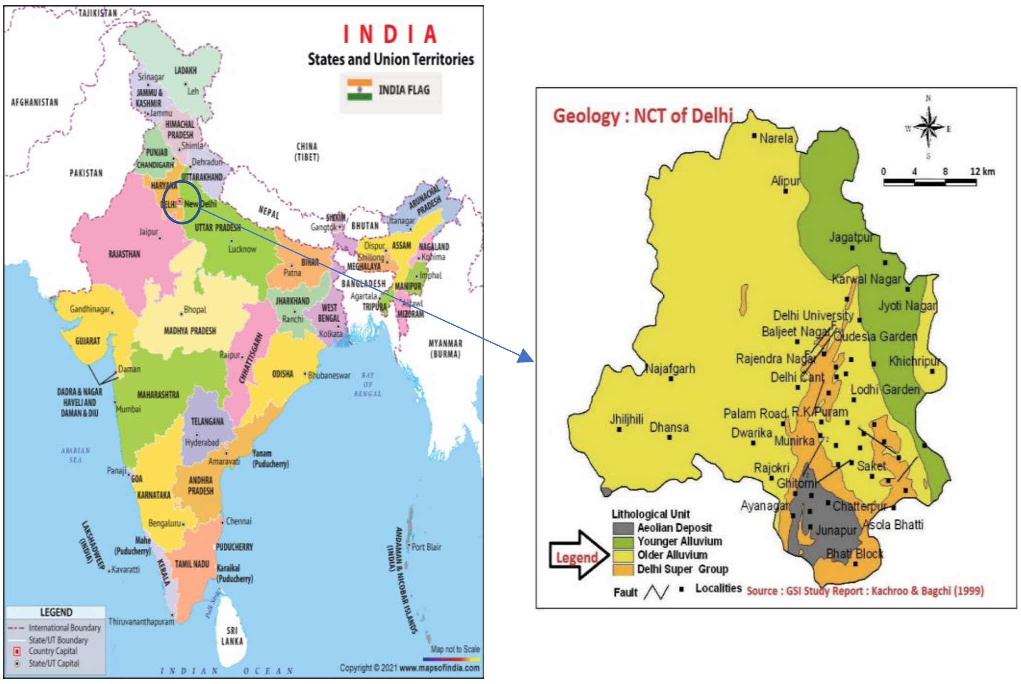


Figure 1.1: Map of Study Area

Chapter 2.

Literature Review

2.1. Delhi's Groundwater: A brief understanding

2.1.1. Availability of Ground Water

Groundwater has a net availability of 30650 hams. 33905 hams were calculated to be the yearly groundwater recharge in its whole. The Contribution of other sources of recharge in groundwater are more than rainfall recharge in the tehsils of Najafgarh south west district of Delhi; Narela, & Saraswati Vihar which are in the western district of Delhi. The least amount of groundwater recharge occurs each year in the central district. The anticipated annual groundwater draw (as of 2013) is 38,777 hectares, with Najafgarh Tehsil having the biggest amount, followed by Saraswati Vihar and Narela Tehsils, where irrigation and industrial pulls are much greater. Five of the state's 27 tehsils are classified as "Safe," seven as "Semi-Critical," and the rest 15 are classified as "Over-utilized.".

Of the 13491 MCM total amount of groundwater resources, an estimated 10284 MCM are salty. Western, South-western , South-eastern districts of Delhi are among the areas with low-quality resources. (CGWB, 2016)

2.2. Depth of groundwater:

Generally speaking, the water table depth in NCT Delhi in 2019–20 ranges from less than 2 m in the Yamuna flood plain areas and sections of the Northwest & West district to more than 65 m, notably in the areas under the Rock Ridges in the centre part, New Delhi districts, and South. The water level in May 2019 ranged from 1.07 to 62.64 m, with shallow levels of up to 5 m bgl in about 14% of the region and deep levels of 20 to 63 m in around 30%. In the remaining portions of NCT Delhi, 56% of the land have water levels that vary from 5 to 20 mbgl. In August 2019, the water level varied from 0.30 to 62.27 m bgl, with shallow water levels up to 5 m bgl in about 19% of NCT Delhi areas and deep water levels of 20 to 63 m in about 31%. 50% of the locations in the remaining parts of NCT Delhi have water levels between 5 and 20 mbgl.(GWYB.GOI, 2021)

As of November 2019, the water level ranges from 0.3 to 63.15 m bgl, with shallow water levels up to 5 m bgl in roughly 16% of six regions of NCT Delhi, and deep water levels of 20 to 64 m in around 32% of NCT Delhi. 52% of the land in the remaining parts of NCT Delhi have water tables between 5 and 20 m bgl. Between January and 2020, the water level ranges from 0.8 to 63.13 mbgl, with shallow water levels up to 5 m bgl in about 17% of NCT Delhi areas and deep water levels of 20 to 64 m in about 31%. 52% of the land in the remaining parts of NCT Delhi have water tables between 5 and 20 m bgl.

According to an analysis of seasonal water level variance compared to May 2019, 66% of monitoring stations in August 2019, 62% in November 2019, and 67% in January 2020 had an increase of 0 to 2 m. Only 1% to 2% of monitoring stations report rises of between 2 and 4 metres. As a result of surge circumstances, roughly 25% to 31% of the monitoring stations show a fall in the range of 0 to 2 m, and the remaining 0% to 4% in the range of 2 to 4 m. (CGWB 2019-20).

2.3. Recharge areas in Delhi

Recharge regions have been determined using NCT Delhi's water table elevation data. The recharging areas are the flood plains region of yamuna river and ridge of Delhi. Natural artificial recharge such as direct recharge from rainfall, seepages through canals, irrigation, buildings of water-conservation, etc.(CGWB, 2021)

2.3.1. Land Use utilisation of Delhi

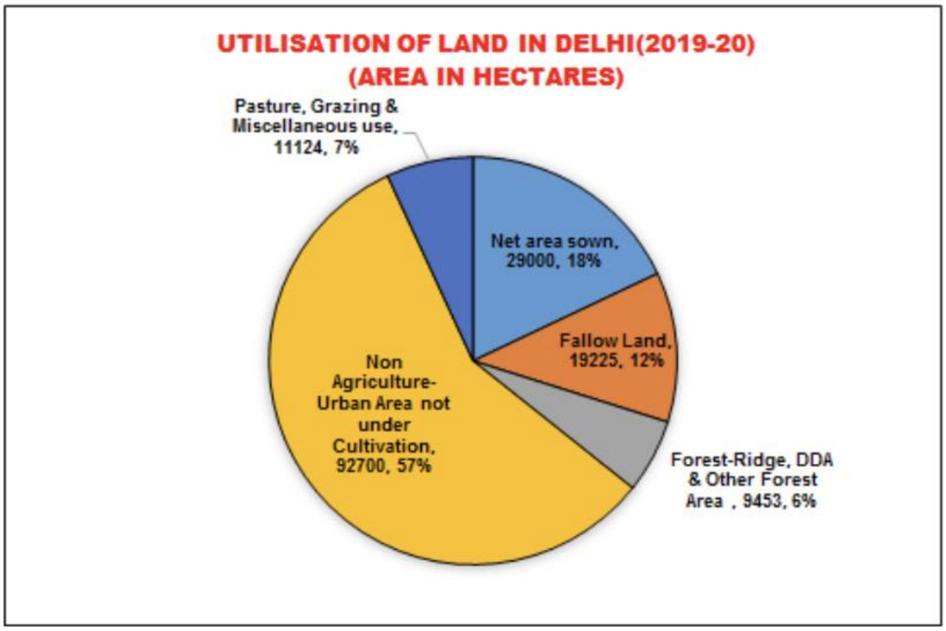


Figure 2.1: LULC Delhi chart

Source: Ground water year book, Ministry of Jal shakti, CGWB

Table 2.1: land use land cover table of Delhi

Landuse Class	Area (sq km)	Percentage of total area
Agriculture Land	572.242	38.57
Forest Area (Ridge)	100.776	6.79
Rural Habitation	46.762	3.15
Wasteland	9.383	0.63
Water Body	26.075	1.76
Urban	728.478	49.10
Total	**1483.716**	

According to land records for the NCT dated Delhi, which cover 1,474.8 square kilometres, only 192.25 square kilometres are suitable for cultivation, and nearly 435 square kilometres are roughly suitable for cultivation or agricultural areas. This means that more than 57% of the area is not suitable for cultivation. Nearly 6% of the entire area is covered by forest, primarily in ridge areas as mentioned and in additional pockets under DDA and government forest land.

2.3. Rainfall of Delhi

The state receives 611.8 mm of rainfall on average per year. The monsoon months of Delhi, India are July, August, and September account for about 81% of the yearly precipitation. Though rainfall is also received even during winter and during the months of before and after monsoonal season.ie. throughout the year. The annual variation in the rainfall parameter has great significance in ground water susceptibility. Annual year of 1933 had the highest rainfall, at 251% of normal, throughout a 113-year period from 1901 to 2013. 1951 was the year with the fewest raindrops, and only 44% of the typical annual total deductions were made during that year.(Shi et al., 2003)

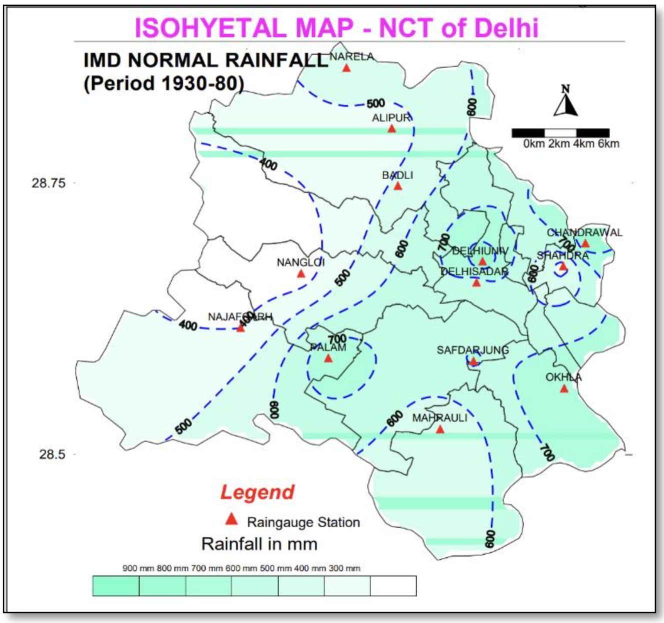


Figure 2.2: Delhi's NCT isohyetal map

2.9 Geomorphology

The hydrogeological condition in the NCT of Delhi, which is characterised by the prevalence of various landforms developed on various geological formations, governs the availability of groundwater. Three major geomorphic units can be used to categorise the entire NCT, Delhi area:

- Rocky surface
- Older alluvial plain
- Yamuna river floodplain

Rocky surface: The rocky surface, which stretches from Mahipalpur in South Delhi to in the wazirabad region in the north, is made up of structurally regulated relict linear ridges, isolated mounds, Delhi Supergroup rocks, and isolated hills. The ridge splits in two south of Mahipalpur, with one arm reaching as far as Mandi, further south, and the other turning to the southeast and reaching as far as Okhla. The elevation escalated up to 362 metres above mean sea level, which progressively decreases toward the north. This can be evident from the exposed rock on west bank of the Yamuna river which flows near Wazirabad region of Delhi.

Older Alluvial Plain: The Older Alluvial Plain is the slightly undulating ground on both sides of the rocky surface. This area is isolated from the bluff and Yamuna flood plain. This unit is further broken down into a number of different sub-units based on the morphological expressions or features:

(i) Older Alluvial Plain of Najafgarh I Plain Maidan Garhi
(ii) Delhi Older Alluvial Plain
(iii) Plains

Najafgarh Sand dunes and sand layers partially encircle an earlier alluvial plain that once covered the western and southwest portions of the region. A somewhat higher plain that is a part of the Chhatarpur watershed is the Maidan Garhi Plain.

Yamuna River Floodplain: A major geomorphic unit, the Yamuna River Floodplain occupies the northern, north-eastern, and eastern portions of NCT. The floodplain's breadth varies from 15 to 17 kilometres north of Narela. The Yamuna River's ancient floodplain serves as evidence of its extensive lateral migration. The development of groundwater in this belt has good potential. An erosion terrace is created. Yamuna the Active Flood Plain is a broad area that is bordered by levees on both the eastern and western sides, and it is certainly susceptible to yearly and intermittent flooding because it is in the Yamuna River's flood direction and flood margin zone.

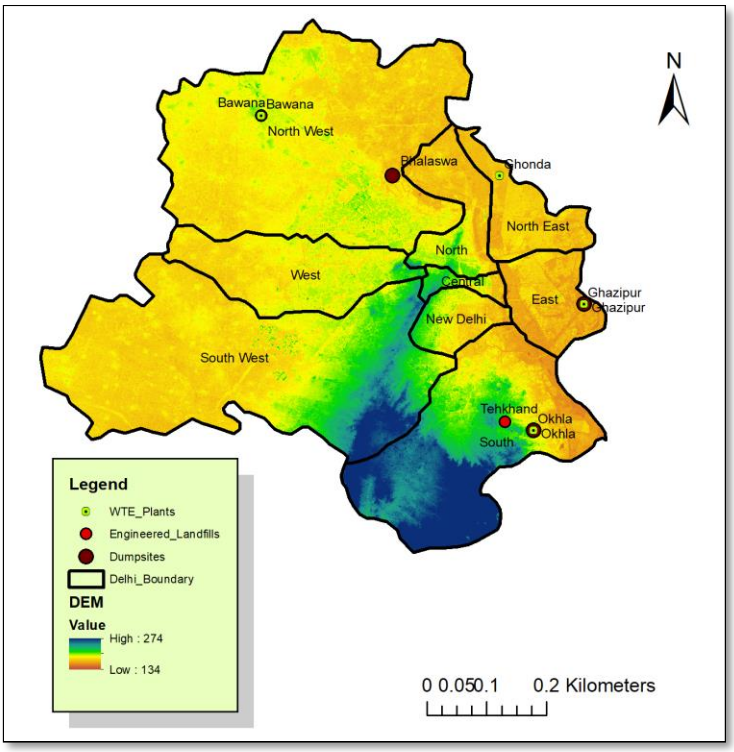


Figure 2.3: DEM of Delhi (ht. in metre above GL)

2.9 Drainage map of Delhi

The Najafgarh Drain, which is approximately 39 kilometres extended and streamed in a north-easterly direction until joining the Yamuna River at Wazirabad in north Delhi, is one of the seven drainage basins that make up the National Capital Territory of Delhi. Barapullah drain, supplementary drain, and third drain. Wildlife refuge area (iv), Shahdara area drainage (v), Bawana drainage basin (vi), and other drainage system directly draining into the Yamuna river of Delhi region on the right bank (vii). Along the Yamuna River's flood plains, swampy places are frequent.

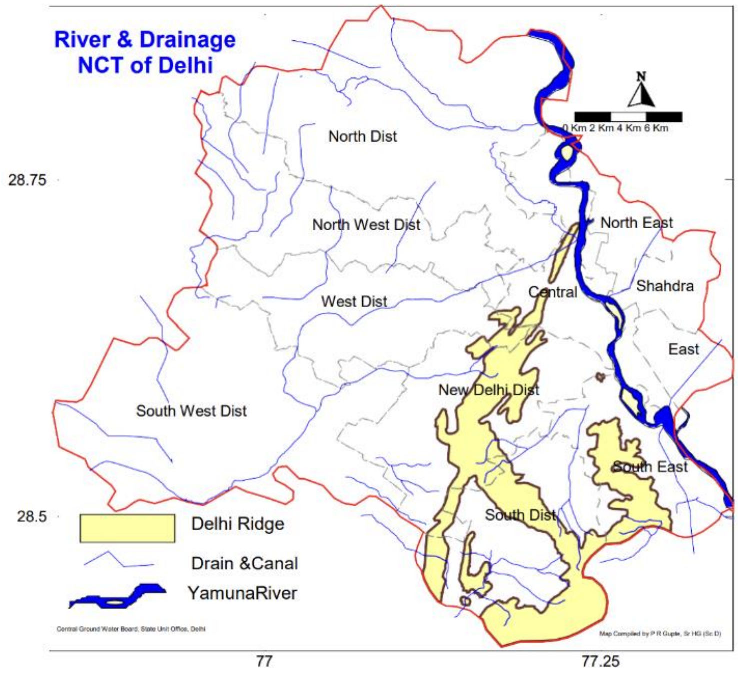


Figure 2.4: Drainage map of Delhi

The eastern portion of the Delhi region is traversed by the Yamuna River. Along the N-S axis, the river oscillated in a sideways motion. It moved steadily to the east at the beginning, then moved to the west in the last phases due to depression brought on by N-S trend mistake (Sarkar et al., 2016) The Yamuna River's right palaeobank lies north of Delhi, near Narela, and from there it changes virtually east-west at Wazirabad before continuing to follow the ridge border further south. North of Delhi, there are a lot of Yamuna River paleochannels and abandoned channels.

2.9 Aquifer information

One main aquifer system is made up of several sand zones that make up various local aquifers in the alluvial regions of the NCT of Delhi. Based on several hydrogeological maps and a groundwater survey, three distinct possible groups of aquifers were discovered and categorised in the NAQUIM study at a depth of 450 metres below earth.

1. Group I of Aquifer – up to 65 mbgl (unconfined)
2. Group II of Aquifer – Between 65 to 200 m mbgl (Confined/Semi-confined)
3. Group III of Aquifer – Between 200 to >300 m mbgl (Confined)

The location of the aquifer reveals the presence of an extensive pile of alluvial deposits on both sides of the quartzite ridge, which runs in a North East-South West orientation. Along the Yamuna river's eastern shore, there is a lot of sand. While silt/silt with kankar is plentiful in the south-west and south regions of Delhi, clay is abundant in the north and north-west. Sand, silt, and kankar combine to form possible aquifer zones in alluvium. Potential aquifers are formed by worn and cracked zones in quartzite. New Delhi The bedrock of NCT Delhi is composed of quartzite, which is exposed in certain places and covered by alluvial sediments in others. The alluvium layering the quartzite gets thicker as it gets closer to the outcrops. As of the folding and faulting of geological developments throughout the Precambrian and subsequent stages, the basement topography of the NCT of Delhi is extremely unlevel and exhibits the presence of subsurface hills and valleys.(CGWB, 2016)

In earlier alluvium, it was discovered that the yield of exploratory wells ranged from 8 to 35 m3/hour with pumping from 6 to 24 m. Younger alluvium wells typically produce between 100 and 210 m3/hour with an extraction range of 5 to 11 metres. Additionally, wells bored in the Chhattarpur basin logged an extraction of 12 to 20 metres and a production of 7 to 14 m3/hour.

One estimate puts the NCT Delhi's average infiltration rate at 135 mm per hour.

2.9 Hydrogeology

Groundwater movement and occurrence in the subsurface aquifer system are influenced by topographical features, geological features, macroclimates, water yield, and the water-holding capabilities of the bedrock and rock in the aeration and saturation zones. During water level monitoring, the water level is determined as the elevated surface of the saturation zone. The water level for wells that pierce closed aquifers represents the pressure or piezometric head there. Prior to building a monitoring network, it is crucial to have a thorough grasp of the location's aquifers' layout and geometry in order to monitor water levels effectively. With its broad, gently undulating plains, which are subjugated by the Yamuna River, low rectilinear ridges, and solitary hummocks, the NCT of Delhi reflects an established topography. The Yamuna River, the Aravalli Mountain, and the plains amid, which were created by Recent era alluvium remnants, lead the Delhi's physiography.

In recent research conducted by CGWB under the NAQUIM Project, the precise regional aquifer geometrical levels in the NCT, Delhi, has been established. The following aquifer map was created using all available data about subsurface aquifer configuration. Central Ground Water Board under the Ground Water Exploration Programme had deciphered the data from lithological and geophysical logs of exploratory wells, as well as their interpreted records of various geophysical studies, etc.

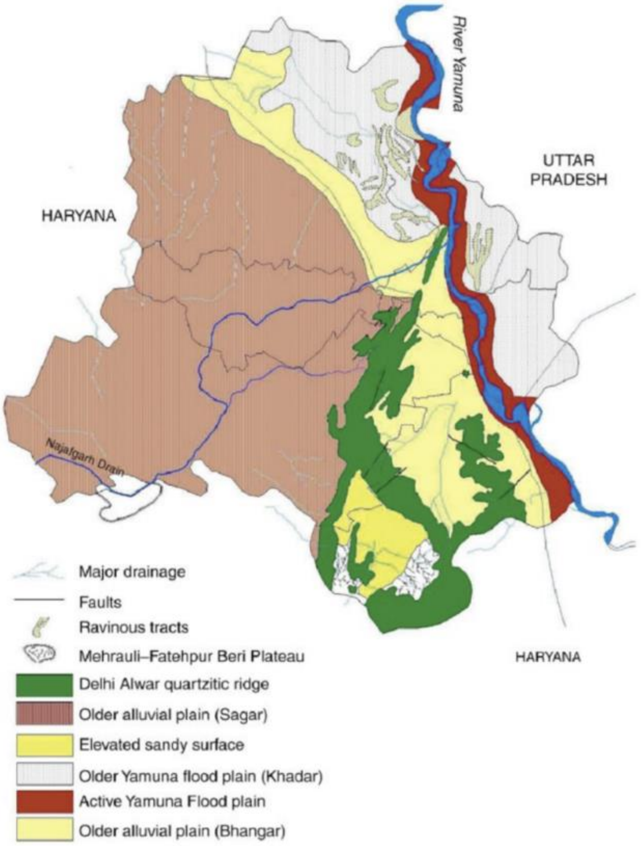


Figure 2.5: Delhi's geomorphological map

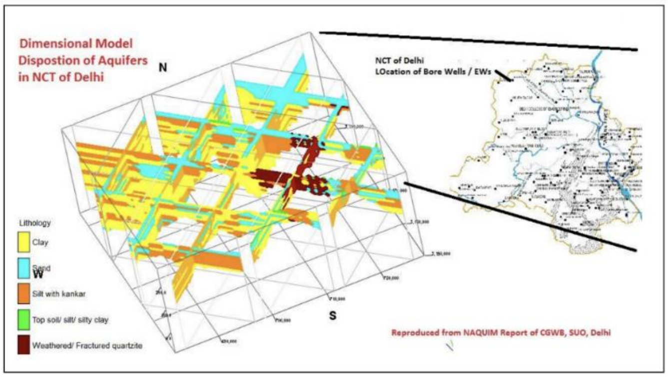


Figure 2.6 Dimensional Model of Aquifer Deposition in the NCT of Delhi; Source: Report for NAQUIM and CGWB yearbook

2.8 Fresh and Saline water Interfaces

In the shallow depth range of 10 to 30 mbgl, the water is fresh, and below this depth, it degrades. Najafgarh drain in the NCT of Delhi has notable variations in groundwater quality along the segment at shallow depths. The transition between fresh and brackish water is about 10 mbgl away from the entrance to this sewer in the western region close to Gummanhra. In the northern part, this interface is seen at 30 m bgl and gets deeper. Additionally, it is reinforced by the fact that the eastern side has a wider range of water quality options than the western side due to the general groundwater movement in the same direction and the Najafgarh drain's ability to replenish groundwater. In wide-ranging, the quality of groundwater is fresh at shallow depths between 10 and 30 m bgl and degrades below this level. In the western half of the sewer, the formation is quite salty below a depth of 65 m, but it is good there.

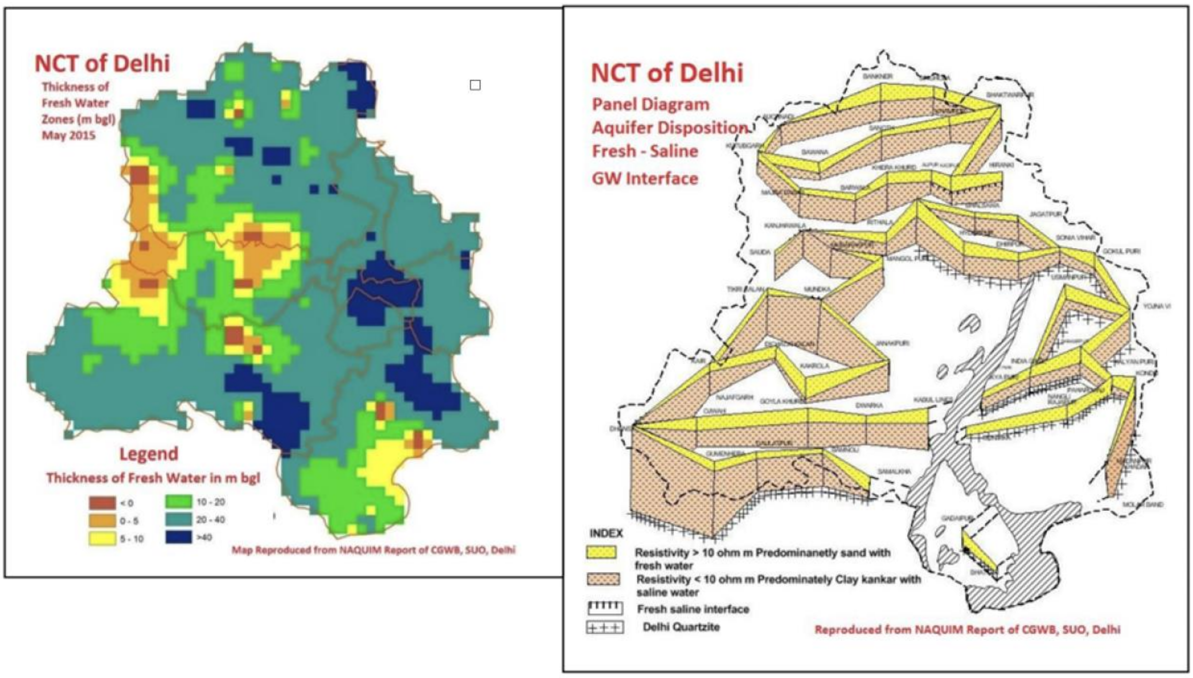


Figure 2.7: Delhi panel diagram for the interaction between fresh and salt water

The figure on the right's perusal reveals that bedrock is found across the Southwest district of NCT Delhi, including in the communities of Dhansa, Samalkha, Kabul Lines, and Jhuljhuli, where the area's fresh/saline water interface also varies significantly. The fresh water layer is somewhat deeper along the Najafgarh Drain and in two depressions, Gummanhera and Pindwalan Kalan, although it is only up to a depth of 25 to 28 m bgl in the rest of the area. The district's western regions have a limited amount of fresh water zone thickness.

The presence of hardrock with more thickness of fresh water aquifers in the eastern fragment of the district where the fresh-saline water interface occurs at deeper depth, i.e. usually around 80 to 90 m bgl. The saline ground water is present at a very shallow depth at a few locations, like Dhansa,. The depth of the freshwater/saline water interface in Rajokri is being measured to be 150 m bgl.(N. P. Singh, 2010)

The depth of the fresh-salt interface in the West District varies from 25 to 50 m bgl. The freshwater zone is between 10 and 45 metres deep. In areas like Dichaon Kalan and Kakrola, the freshwater-saline interface is deeper and the freshwater aquifers are thicker. Saline water is found at shallow depths in the locations near Janakpuri, Mundka. The freshwater interface's depth in the South district ranges from 75 to 100 metres. The freshwater zone ranges in thickness from 30 to 85 metres. In locations like Gadaipur, Bhatti, and Munirka, hard rock follows freshwater aquifers (Delhi Quartzite). The depth of the fresh-salt interface in the West District varies from 25 to 50 m bgl. The freshwater zone is between 10 and 45 metres deep. In areas like Dichaon Kalan and Kakrola, the freshwater-saline interface is deeper and the freshwater aquifers are thicker. Saline water is found at shallow depths in the locations near Janakpuri, Mundka.

The freshwater interface's depth in the South district ranges from 75 to 100 metres. The freshwater zone ranges in thickness from 30 to 85 metres. In locations like Gadaipur, Bhatti, and Munirka, hard rock follows freshwater aquifers (Delhi Quartzite). Up to a depth of 250 metres, there was no sign of bedrock. The areas along the Yamuna floodplain in the northeastern district have thicker freshwater aquifers. The depth of the freshwater interface varies from 25 to 38 m bgl in the rest of the region, compared to 32 to 50 m bgl in the Yamuna floodplain.

Fresh water sediments are followed by salt water and quartz in New Delhi and the Central District (Delhi Ridge). Localities like Kalyanpuri, Kondli, and Shakarpur have thicker fresh water aquifers in East & Shahdara districts, ranging up to 60 mbgl.

2.8.1. NCT Delhi Hydrogeochemistry

Different groundwater conditions and groundwater characteristics in the National Capital territory of Delhi are a result of various physiological, topographic, and geological variables, and they vary with different depth and location. The present situation primarily affected by the local geological features, intrinsic salinity besides uneven groundwater development.

Groundwater quality in alluvial deposits often declines with depth, though this can vary regionally. In the northwest, western, and portions of the southwestern districts, as well as in lesser regions in the northern and central districts, fresh ground water aquifers are most common and extend to depths of 25 to 35 m. Fresh water can be found up to a depth of 30 to 45 metres in the southern, southeast, and southwest regions, especially in the Najafgarh Jheel region. Regardless of proximity to the river Yamuna, a small region north of the Kamala Nehru Ridge that includes the towns of Dhirpur, Wazirabad, and Jagatpur is distinguished by shallow depths of freshwater aquifers ranging from 22 to 28 m. (Khan & Bidhuri, 2020)

Freshwater aquifers in the Yamuna floodplains often reach to a depth of 30 to 45 metres, and in Palla, they extend to a depth of 60 to 75 metres below which brackish and salt water can be found. In the regions surrounding the ridge, which include downtown Delhi, New Delhi, the southern and eastern portions (ridge area) of the south-western districts, as well as the Chattarpur basin, the groundwater is fresh at all depths. The freshwater zone has a restricted thickness in the majority of the western and southwestern districts in places west of the ridge, where freshwater aquifer thickness typically declines toward the northwest.

2.9 Water Quality Analysis

The CGWA's description of the study area's ground water quality is provided in Annexure-I. The analysis reveals that the pH of nearly all of the samples taken, or in most of Delhi's neighbourhoods, is above the acceptable range. 70% of sites have very hard water, defined as having a hardness more than 300 mg/l. 60% of the samples had total dissolved solids in the range of 1000–1000 mg/l, which is considered brackish. As a result, at 25 °C, the hydraulic conductivity ranged from 291 to 15,220 S/cm. Kanjhawala, in the North West District, reported a maximum concentration of 15,220 S/cm. Bicarbonate (HCO3) is the most prevalent anion, contributing 43% of the total anion (TZ-) mass balance in equivalent units. From 102 mg/l to 658 mg/l of bicarbonate are present in the solution. Southwest 65 District's Bamnauli reported having the highest bicarbonate concentration. In the CO2 soil zone, during parent mineral weathering, or by dissolving carbonates and/or silicate minerals with carbonic acid, bicarbonates are mostly produced.

People who are not acclimated to it experience a saline taste and a purgative effect from drinking water with a greater percentage of chlorine. In 38% of the analysed samples, the concentration of Cl^- exceeds the acceptable limit of 250 mg/l ((BIS:10500, 2012)) and only 8 of the assessed samples surpass the maximum allowable level of 1000 mg/l.

Parts of the N-W & S-W districts have reported isolated pockets of sulphate concentrations that are higher than the maximum allowable level. The high concentration that was found in several samples demonstrates the impact of anthropogenic and industrial activity in the region. When there is too much Mg in the water, a high sulphate content can have a laxative effect. Groundwater samples were found to have fluoride concentrations ranging from 0.09 to 8.19 mg/L.

Large portions of the northwest and southwestern districts, as well as solitary pockets in the northeastern, western, northern, eastern, central, and southern districts, reported elevated fluoride levels. The disintegration of rocks (geogenic) that include fluorine-carrying minerals like fluorite, apatite, and mica or the disproportionate use of phosphate fertilisers and fluorine-containing pesticides and herbicides in th belt of agricultural areas can both lead to fluoride contamination of groundwater.

The 26.6% of the overall cation mass balance is calcium (Ca^{2+}). It is essential for the growth of cells, the neurological system, and the bones. The two main factors that affect hardness are Ca^{2+} and Mg^{2+}. An increased risk of kidney stones may result from long-term consumption of a high Ca content. In roughly 53% and 76% of the tested samples, the Ca^{2+} and Mg^{2+} concentrations are higher above the recommended standards for drinking water (BIS:10500, 2012) of 75 mg/l and 30 mg/l. However, in 9% and 21% of all samples, respectively, the concentrations of both of these ions are higher than the respective maximum permitted limits of 200 and 100 mg/l. Ca in groundwater ranged in concentration from 13.4 mg/l to 810 mg/l.(CGWB, 2016)

2.9.1.HEAVY METAL ANALYSIS

All 60 samples of chromium were found to be within the permitted range. The greatest manganese concentration, 1.168 mg/l, was found at Jagatpur out of 60 sites. All of the locations that were evaluated had iron contents that were within the acceptable range of 1.0 mg/l. At the following locations: Auchandi, Kanjhawala, Nizampur, Ojwah, Peeragarhi DW, Rani Khera DW, and Tikri Kalan, uranium concentrations were found to be higher than the allowable level (30.00 ppb).

2.10 Vulnerablity Analysis

The vulnerability concept can be classified into two notions, namely, intrinsic and specific vulnerability. Intrinsic vulnerability (Civita, M.,1994) is used for represention of the characteristics of the groundwater system (e.g., inherent geological, hydrological, and hydrogeological characteristics) that determine the sensitivity of groundwater to contamination generated by anthropogenic activities irrespective of the nature of contaminants. By contrast, specific vulnerability is used to describe the vulnerability of groundwater to an actual pollutant or group of pollutants. The properties of the pollutants and their relationships with the various components of intrinsic vulnerability has been considered. (Ribeiro L.,2017). For the assessment of vulnerability index, we need not to consider the every parameter of the DRASTIC model of GIS has been argued by the group of research scholar.(Merchant 1994;Barber et al. 1993). Rather as we took the all seven parameters for assessment of vulnerability index is termed as Unperturbed vulnerability index and when a lesser number of prescribed dataset is used to assess vulnerability index ten it is called as perturbed index.

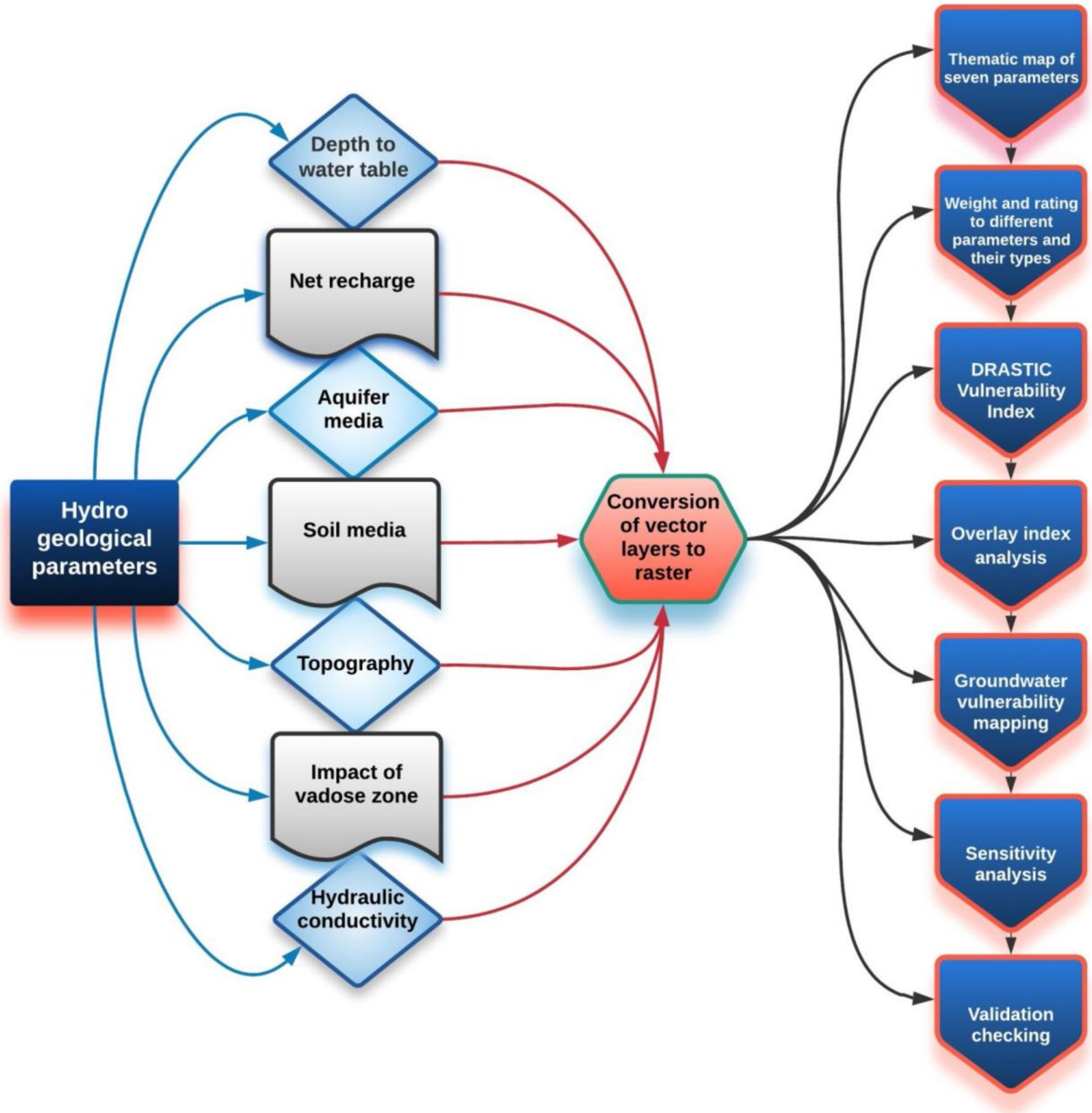


Figure 2.8: Methodological flow chart of vulnerability analysis of groundwater by DRASTIC model with GIS application; Source-Groundwater vulnerability assessment using GIS Article in Environmental Earth Sciences in January 2022

The results of groundwater flow modelling indicate that the direction of groundwater flow is generally to the southeast. The northwest edge has been designated as a groundwater recharge area. The Aluvium aquifer will experience a maximum decrease of about 10 metres by 2030, according to a comparison of anticipated water levels with increased pumping and findings from earlier model simulations. Anthropogenic activities are the main reason for groundwater pollution. There have been nitrate reports around landfills, agricultural land, and sewers.

Similar to this, Najafgarh's industrial zones, landfills, and drains are where heavy metals (over allowed levels) are most commonly found. In isolated compartments in Khanpur, Kanjhawala, Jagatpur, Rajauri Garden, Dhansa, Mahipalpur, and Greater Kailash, pesticides and bacteriological parameters were also reported.(CGWB, 2016)

Table 2.2 Literature review and its key learnings

S. No.	Theme	Key Findings	Citations
1	DRASTIC Model for Vulnerability Index	Classify our parameters to find Vulnerability zones in the study area.	Mahbubur Rahman, *et.al*. 2021.
2	DRASTIC Implementation for Delhi	Applicability of DRASTIC in Delhi with aquifer media and strata available in Delhi.	National Aquifer Management Program (NAQUIM) Report, 2020-21.
3	Aquifer Media and Soil profile in Delhi	Aquifer media profile for Delhi and various classes as required by DRASTIC.	Central Ground Water Board, 2016
4	Cause & effect for ground water in Delhi	Various Ground Water related issues in Delhi including fluctuations in the ground water depth and the major pollutants present in the NCT region.	Ground Water Year Book, 2020-2021.
5.	Ground water condition of Delhi	Present ground water situations and the issues associated.	Aditya Sarkar.*et.al.* 2016.
6.	Status of Solid waste generation and treatment & Disposal	Quantity of Solid Waste generation and the Treatment & Disposal sites the authorities have. What is the major pattern followed in installation of these facilities. Mapping of Facilities.	D.K Singh, Delhi Pollution, Control Committee,2020

Chapter 3.

Materials and Methods

This section covers the study's methodology as well as the interim findings that contributed to the conclusions and outcomes. DRASTIC formulations and the underlying ideas for each parameter, regarding influencing vulnerability and working to contribute to it.(Awawdeh et al., 2015)

3.1. Methodology

In the study, DRASTIC was utilised to determine the city's ground water vulnerability. For proper operation, the DRASTIC method for vulnerability index needs the following data.:

3.1.1. **D**epth of ground water,

3.1.2. Net **R**echarge,

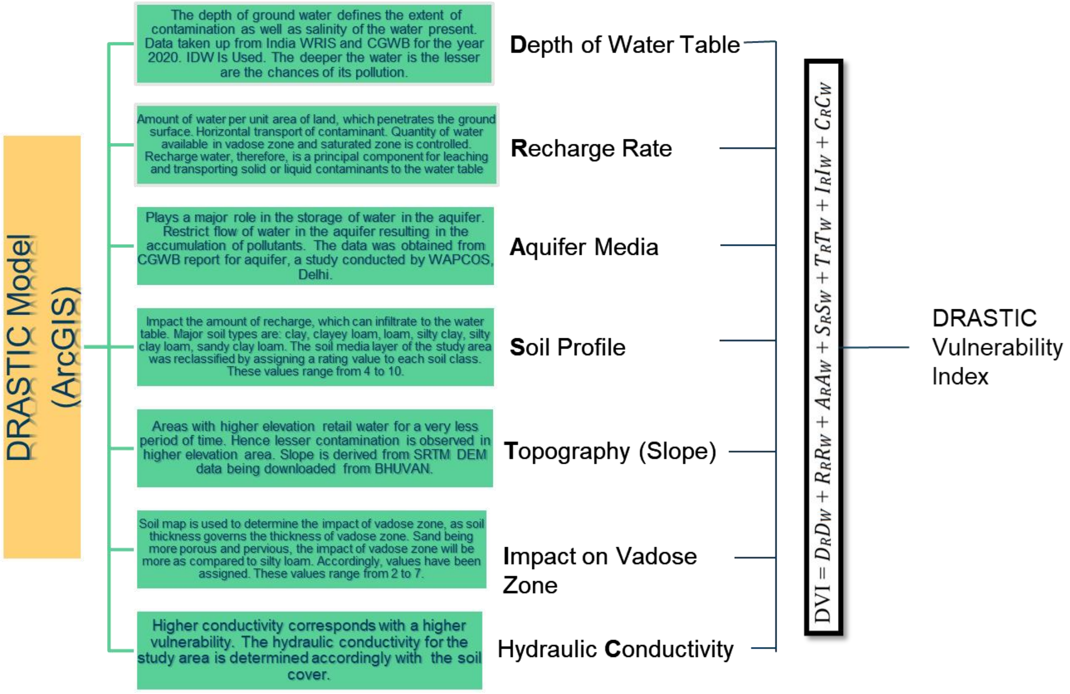
3.1.3. **A**quifer media,

3.1.4. **S**oil media,

3.1.5. **T**opography information,

3.1.6. **I**mpact on Vadose zone,

3.1.7. and hydraulic **C**onductivity of the study area.



The depth of ground water defines the extent of contamination as well as salinity of the water present. Data taken up from India WRIS and CGWB for the year 2020. IDW Is Used. The deeper the water is the lesser are the chances of its pollution.

Amount of water per unit area of land, which penetrates the ground surface. Horizontal transport of contaminant. Quantity of water available in vadose zone and saturated zone is controlled. Recharge water, therefore, is a principal component for leaching and transporting solid or liquid contaminants to the water table

Plays a major role in the storage of water in the aquifer. Restrict flow of water in the aquifer resulting in the accumulation of pollutants. The data was obtained from CGWB report for aquifer, a study conducted by WAPCOS, Delhi.

Impact the amount of recharge, which can infiltrate to the water table. Major soil types are: clay, clayey loam, loam, silty clay, silty clay loam, sandy clay loam. The soil media layer of the study area was reclassified by assigning a rating value to each soil class. These values range from 4 to 10.

Areas with higher elevation retail water for a very less period of time. Hence lesser contamination is observed in higher elevation area. Slope is derived from SRTM DEM data being downloaded from BHUVAN.

Soil map is used to determine the impact of vadose zone, as soil thickness governs the thickness of vadose zone. Sand being more porous and pervious, the impact of vadose zone will be more as compared to silty loam. Accordingly, values have been assigned. These values range from 2 to 7.

Higher conductivity corresponds with a higher vulnerability. The hydraulic conductivity for the study area is determined accordingly with the soil cover.

$$\mathrm{DVI} = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W$$

Figure 3.1*: Method for DRASTIC*

The sources of the necessary information, which are listed in the following sections, include both literature and a number of web platforms. As a result, a GIS-based output is produced.

To find the vulnerability, processing of the data indicated above that was collected from the relevant platform is required. The variables are crucial for valuing one another because they are dependent on one another (Awawdeh. et al., 2015). In DRASTIC, the variables have been given weights based on their significance and contributions so that an objective assessment may be made. The range of the weighting is 1 to 5. The criteria have also been broken down into categories or important media types that affect pollution potential using a scale of 1–10.

The rating assists in discovering relative comparisons between the criteria, effectively bringing them together for comparison. The rating is given following an assessment of its relative importance to pollution potential.

In DRASTIC method 'effective' weight of each parameter has compared with its assigned weight which further has been given theoretically to them on the basis of available literature and thus impact of each parameter will led to vulnerability index assigned by using following formula

$$W = (P_r P_w / V) \times 100$$

where, W refers to each parameter effective weight,

P_r and P_w each parameter indicates rating and weightage.

V is the overall vulnerability index.

Those parameters which have more impact on the overall result of the model only if there is greater operative weight than theoretical weight of any one or more parameter that indicates (Majandang and Sarapirome 2013)

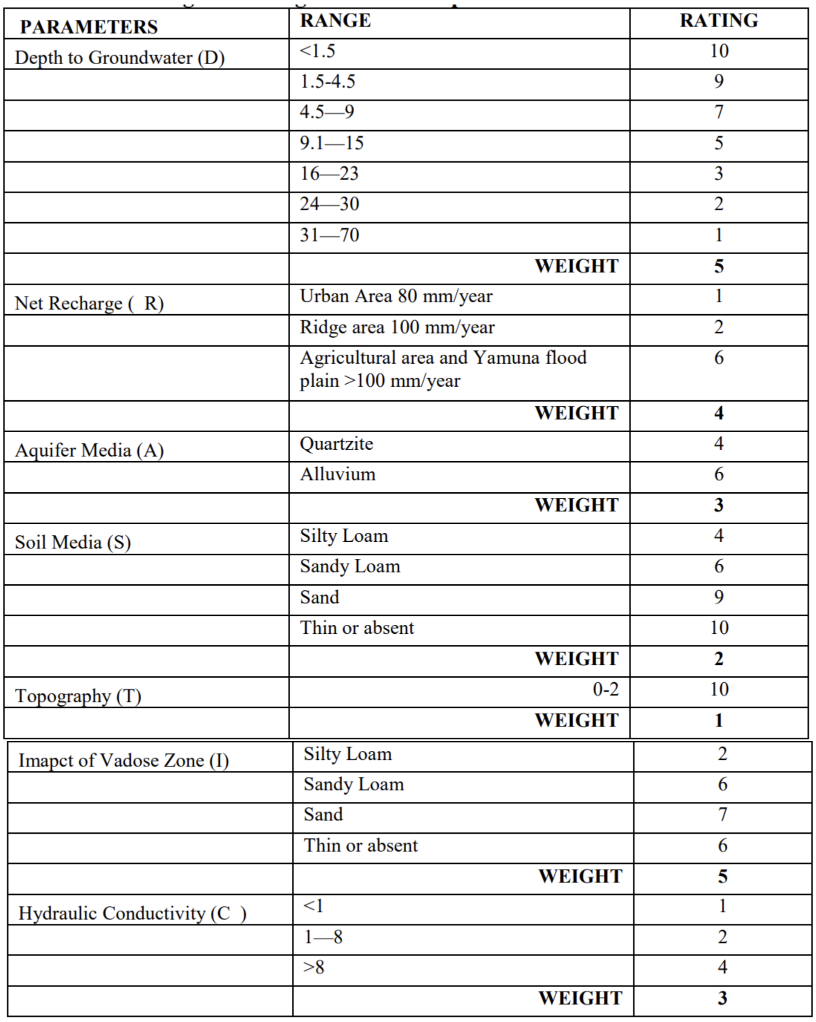
The DRASTIC Vulnerability Index (DVI) is calculated using the following equation:

$$\text{DVI} = D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W$$

Where: R = rating and W= weight (for different parameters)

The Drastic Vulnerability Index is calculated using the aforementioned equation within the GIS Platform itself (DVI). The locations that are more susceptible to ground water pollution can be easily identified once the Index has been calculated. A higher DVI value indicates a greater vulnerability to contamination. Despite the fact that DVI only offers a relative assessment of vulnerability as opposed to an absolute digital output value (Awawdeh et al., 2015). The table below, which illustrates what values of the parameter imply how much rating and holds how much weightage, was collected from the literature.

Table 3.1: Classification used for DRASTIC Model



PARAMETERS	RANGE	RATING
Depth to Groundwater (D)	<1.5	10
	1.5-4.5	9
	4.5—9	7
	9.1—15	5
	16—23	3
	24—30	2
	31—70	1
	WEIGHT	**5**
Net Recharge (R)	Urban Area 80 mm/year	1
	Ridge area 100 mm/year	2
	Agricultural area and Yamuna flood plain >100 mm/year	6
	WEIGHT	**4**
Aquifer Media (A)	Quartzite	4
	Alluvium	6
	WEIGHT	**3**
Soil Media (S)	Silty Loam	4
	Sandy Loam	6
	Sand	9
	Thin or absent	10
	WEIGHT	**2**
Topography (T)	0-2	10
	WEIGHT	**1**
Imapct of Vadose Zone (I)	Silty Loam	2
	Sandy Loam	6
	Sand	7
	Thin or absent	6
	WEIGHT	**5**
Hydraulic Conductivity (C)	<1	1
	1—8	2
	>8	4
	WEIGHT	**3**

Moving forward necessitates a brief explanation of each parameter's impact on vulnerability as well as the methodology used to gather data for each one.

Water table depth (D): The depth of groundwater, or the level at which water is accessible from the surface, determines how contaminated and salinized the water is. Vertical thickness of earth to the upper level of water is referred by Water Table Depth. The greater will be the depth of aquifer table has lesser will be the possibility of vulnerability as it takes further time to spread into the aquifer. Rather, shallow aquifer will have slightly lesser depth from surface and more susceptible to pollutants (physical and chemical) will quickly reach to aquifer. The probability of attenuation increases with increasing water depth since longer travel distances are implied by higher water levels. Because it offers the extreme possibility for oxidation due to presence of oxygen in atmosphere, the depth of the water is also significant. The width of the substrate through which the percolated water must travel before attainment of the aquifer is being determined by D. (Rahman et. al ;2008), stated that deterioration processes of dispersive contaminant and sub-surface materials such as air, mineral, and water, the degree, extent, physical and chemical attenuation have been the direct influence on and deterioration processes of dispersive contaminant and presence of sub-surface materials such as air, mineral, and water. The most recent data available for each district's ground water depth was obtained from India WRIS and CGWB for the year 2020. The Inverse Distance Weighted tool (IDW) of interpolation in GIS has then been used to interpolate the excel sheet so that it can be displayed on the map. Although there are fewer chances of contamination the deeper the water is, it still needs to be at a specific depth to suit the needs of the population.

The Maximum and minimum values found as 22.00 feet bgl of North Delhi,(2022) and 2 feet bgl of North East Delhi,(2022) respectively. The further classification has been given in Drastic Model.

Net Recharge (R): Net recharge refers to the amount of precipitation or other source of water which penetrates into the sub surface zone and eventually reaches to the aquifer.The volume of water that is added to the groundwater per unit of area is known as net recharge. It transfers various impurities both physical and chemical which transmissive from vadose zone to the aquifer. The movement of water from the vadose zone to the saturated zone is aided by the recharge. Greater scope to mixing of contaminants to the saturated zone has been indicated by higher amount of net recharge. Usually, the LULC method was used to determine the net recharge but in this study region rainfall data were collected from IMD (Indian Meterological Department, 2021-22). The WAPCOS aquifer management plan report's method for classifying net discharge takes into account the land use. The amount of contamination transfer can be estimated by looking at the net recharge. Higher recharge values might be a sign of increased pollution susceptibility.

Aquifer Media (A): Aquifer media plays an important role in the storage of water in the aquifer. Physical state of the rock structure which is the place for groundwater storage used to denote the same. Attenuation of pollutants has been controlled by unconsolidated or consolidated rocks with different grain size. Apart from storage these also tend to stop the flow of water in the aquifer resulting in the accumulation of pollutants leading to a higher vulnerability w.r.t pollutants. (Collins et al., 2016). The aquifer media data was obtained from CGWB report for aquifer, a study conducted by WAPCOS, Delhi. On the basis of grain size we have allocated the value with the highest rate of 6 to sand and gravel and 2 to clayey silt that is the lowest ones. Its high permeablity and less attenuation characteristics le to high potentiality to pollution. This parameter was assigned by medium weight (3) as shown in the classification table.

Soil Media (S): Pollutant percolation into the water table is determined by the soil media. The uppermost weathering part of Earth Crust. The material composition of the soil controls the permeability of water. Passively, it acts as a source of contamination for the aquifer. The soil media affects how pollutants migrate vertically. Higher soil permeability increases vulnerability because contaminants are more likely to enter the water table of the region. The soil media data were discovered through the study of NAQUIM data. The soil media has been reclassified on the basis of Drastic characteristics into 4 i.e. silty loam, sandy loam, sand, thin or absent which further rated as 6,4,6,9 respectively with the cumulated weightage of 2 amongst the 7 parameters.

Topography (T): Elevation is crucial in the contamination process since areas at higher altitudes only use water intermittently. Earths nomenclature and its significance is highly predicted by the slope. The variation in the slope is proportional to the runoff system. The higher slope angle, more will be the runoff velocity and which led to less vulnerable to contamination. Thus, higher elevation areas exhibit less pollution. (Awawdeh et al., 2015) pollution (Collins et al., 2016) Slope is calculated using SRTM DEM information that is downloaded from BHUVAN. The rating amongst the slope classes be done at 0-2, 2-6, 6-12, 12-18, >18. with the rate of 10,9,5,3,1 respectively. Effective weightage allotted minimum to this parameter as 1(Collin et al., 2016).

Impact on Vadose Zone (I): The un or partially-saturated soil layer above the water table is referred to as the vadose zone. Grain Cracks, Joints and Pores acts as percolating media of water to aquifer. Vadose zone thickness is inversely proportional to the pollutant movement to Groundwater and vice-versa. The characteristics of the vadose zone determine how toxins are transported into the water table (Collins et al., 2016). A vadose zone with several fractures is more prone to pollution. The analysis of NAQUIM Data was used to determine the vadose zone. This is being catergorises into 4 silty loam, sandy loam, sandy & thin or absent. The sample data has been interpolated by IDW for the region and helps in preparation of Thematic map with four classes rated as 2,6,7,6 with an effective weightage of 5 as per its significance in the vulnerability of ground water.

Hydraulic Conductivity (C): The pace at which groundwater flows is controlled by hydraulic conductivity. The transition ability under the specific headloss of within an aquifer depends on hydraulic gradient of an aquifer. It helps in controlling the movement and spreading of contaminant from particular point to the areas. A higher vulnerability is correlated with a higher conductivity (Machiwal et al., 2018b). In present study 64 sample locations were taken from CGWB report. The data is reclassifying as 1-3, 3-5, 5-6, 6-9, 9-12. This reclassification is being rated as 1,2,3,4,5 respectively with the effective weightage of 3. The standard values for the soil media cover are used to calculate the hydraulic conductivity for the research region. ((Bradley et al., n.d.)).

Finally, all seven thematic maps were overlaid by Overlay Index Analysis as well as the weighted sum tool on ArcGIS software. Multiplication of weighted parameters and rated parametrs of each one and linear equation of these parameters have been used for evaluating DRASTIC vulnerability index. Thus final vulnerability map is being generated to indicate which zones have shown highly vulnerable to groundwater pollution

Chapter 4.

Results and Discussion

4.1. Change in Hydraulic conductivity and corelation with the results

In Delhi, salt in groundwater is a regular issue. On the basis of variable electrical conductivity ranging from 1500 mS/cm to 2000 mS/cm for water table depth, it was investigated the depth to the interface between fresh and salt water, which also varies with contours in the groundwater level (Shashank et al., 2005). The Chhattarpur Basin, which is in the southern and southwestern districts of Delhi, and the region next to the Delhi Ridge are where you can find the fresh-salt interface at its deepest point (Shekhar & Sarkar, 2013). In the vicinity of The Delhi Ridge, the depth of the interface varies between 50 and 100 mbgl. The freshwater interface depth was discovered to be less than 40 mbgl in various areas of Delhi. Groundwater that is extremely salty in the city is mostly connected to water extraction, low-lying areas, and discharge zones (Shrestha et al., 2016). They are also known to cause saline enrichment in groundwater, which has been seen in several areas of Delhi and the nearby state of Haryana. Groundwater chloride and nitrate ion concentrations rise as a result of irrigation and water extraction in these locations.

Greater groundwater permeability zones can be found in areas where hard rock is present and when faults are present. During the rainy season, there is also a continual surface flow from the hard rocky, higher elevation places nearby to these areas. Along with that dynamic soil, the area's waterways also have a greater gradient, which results in more water frequently moving into and out of the area. The increased depth of the fresh/saline interface in the southern region is a result of the aforementioned forces operating in concert.(Shashank et al., 2005)

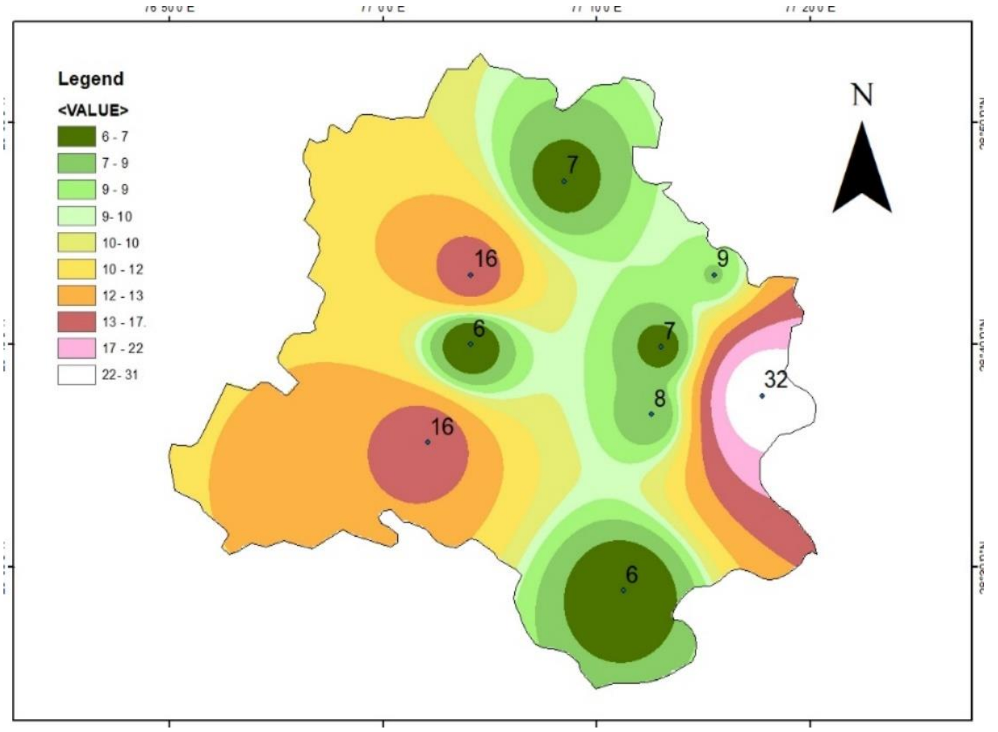


Figure 4.1: Depth of GW table IDW

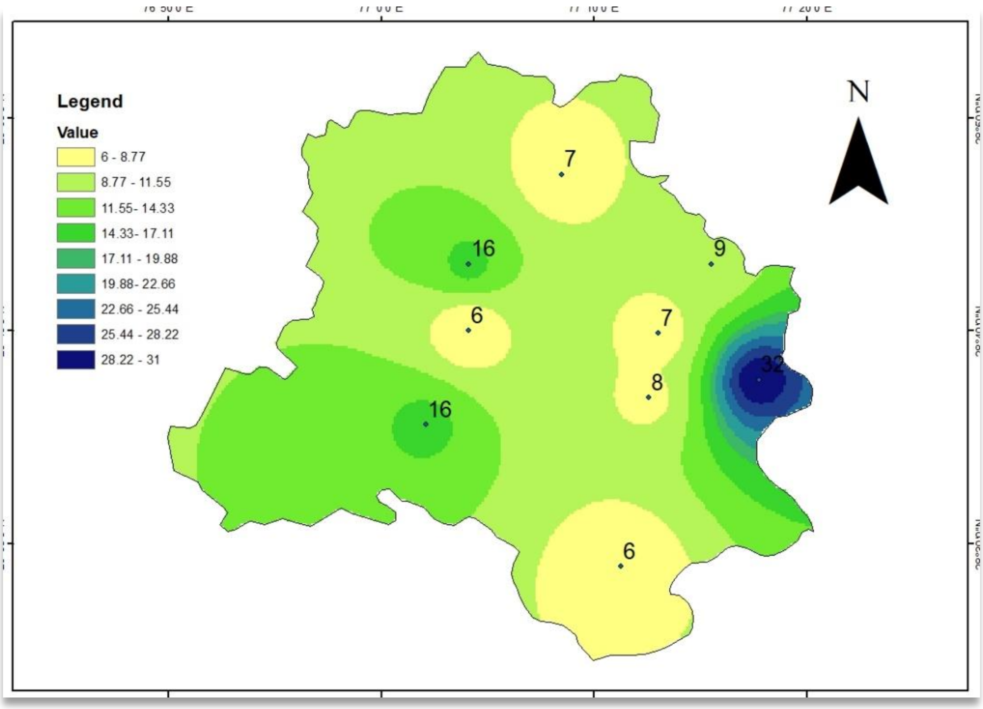


Figure 4.2: Depth of GW table after DRASTIC rating

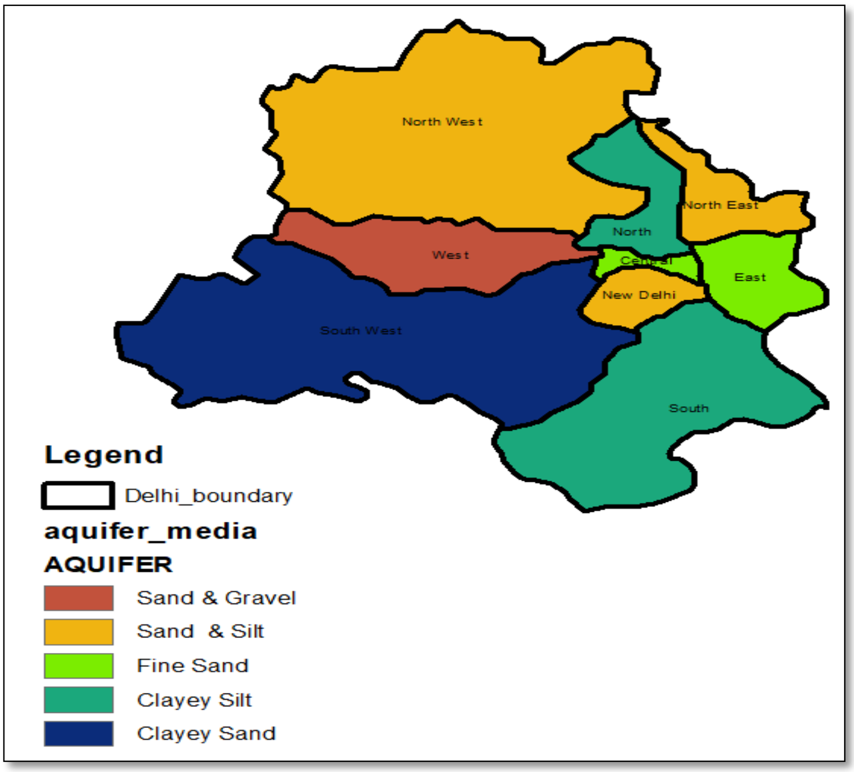


Figure 4.3 Aquifer media map raw

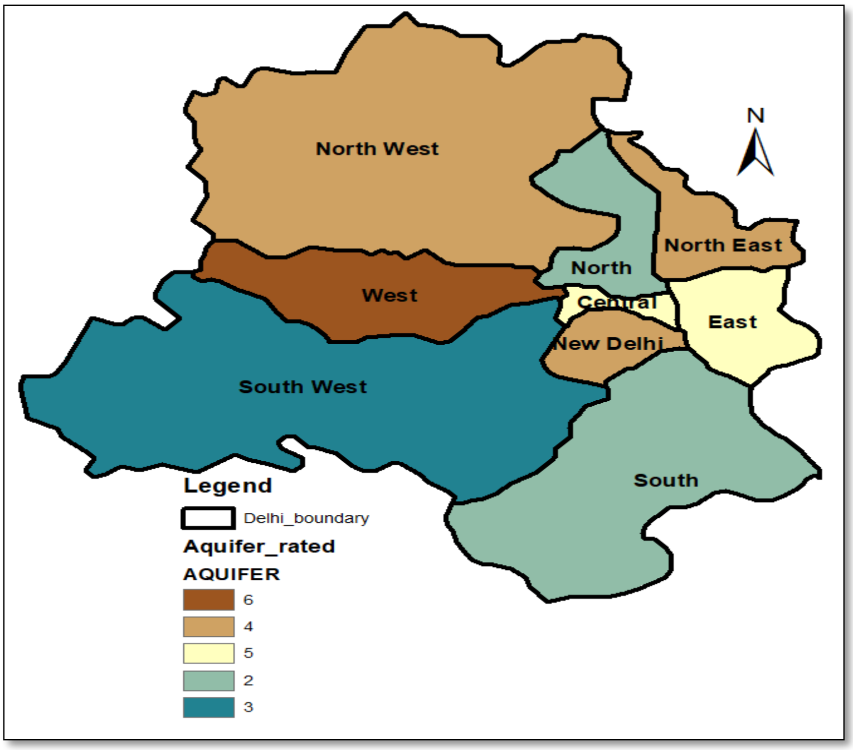


Figure 4.4: Aquifer media map rated as per DRASTIC

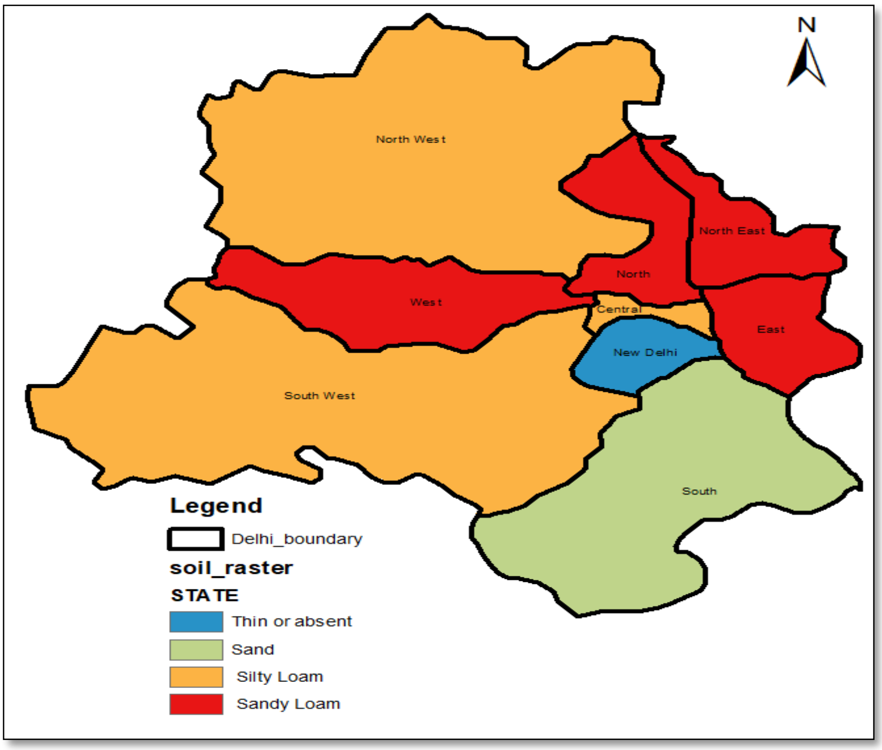


Figure 4.5: Soil media map raw

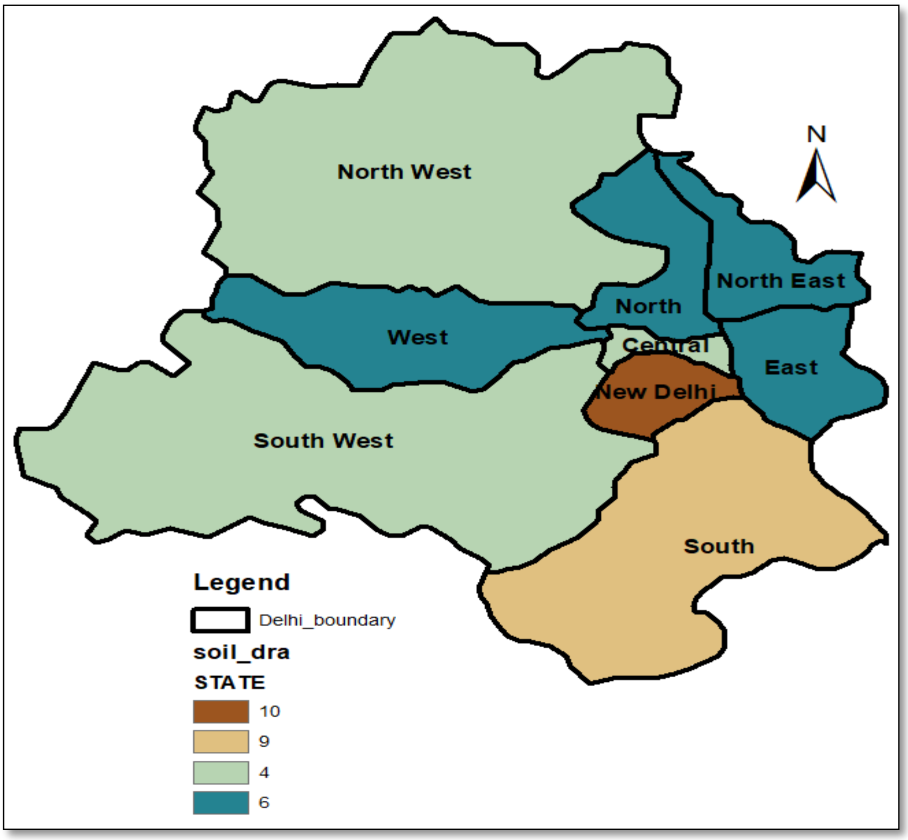


Figure 4.6: Soil media map after rating as per DRASTIC

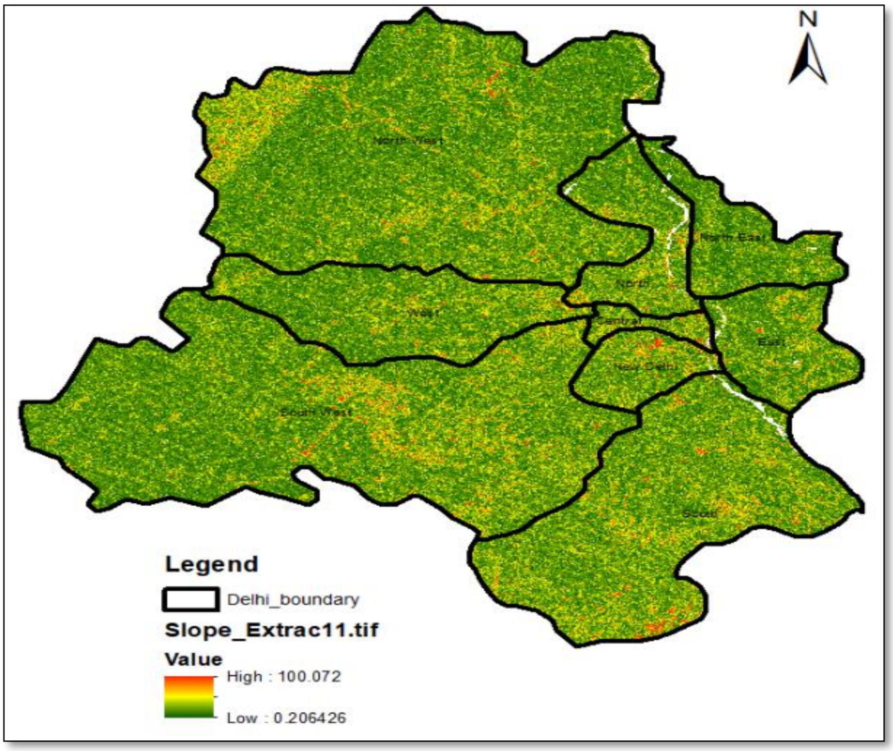


Figure 4.8: Slope percentage map from SRTM DEM

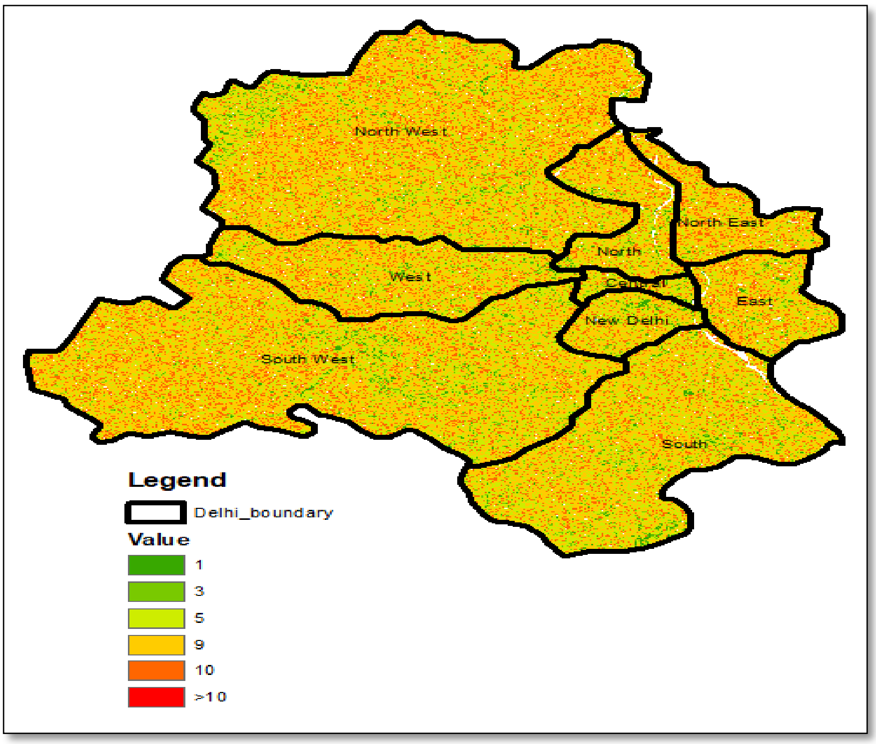


Figure 4.9: Slope percentage rated as per DRASTIC

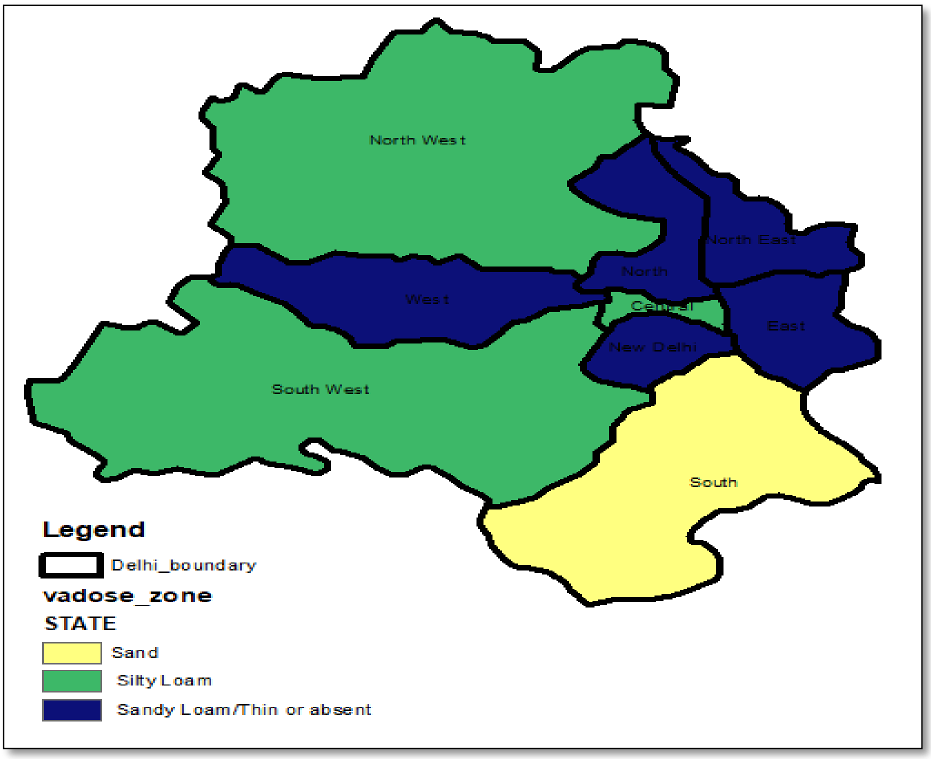


Figure 4.10 Impact on Vadose zone map raw

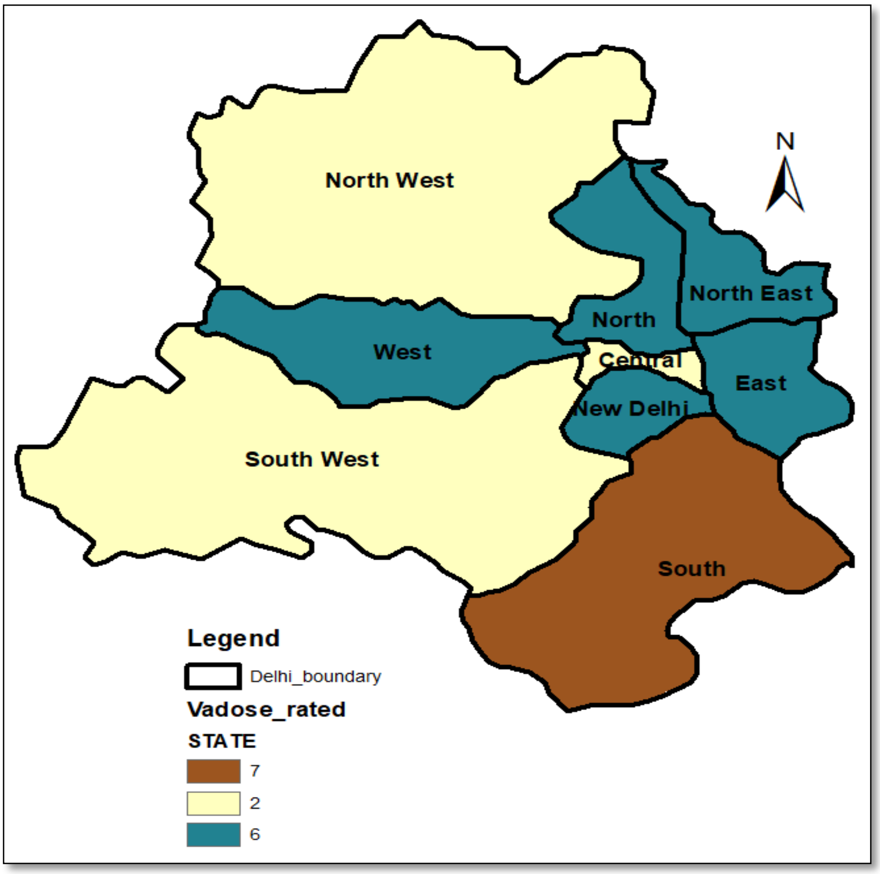


Figure 4.11 Impact on Vadose zone after rating as per DRASTIC

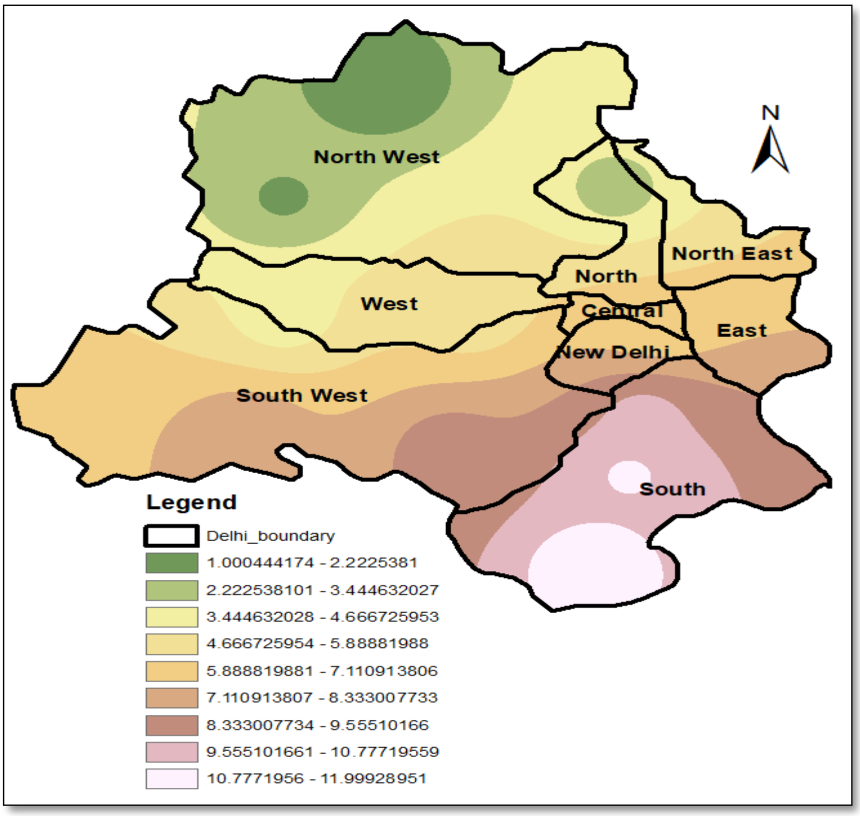


Figure 4.12 Hydraulic conductivity raw map

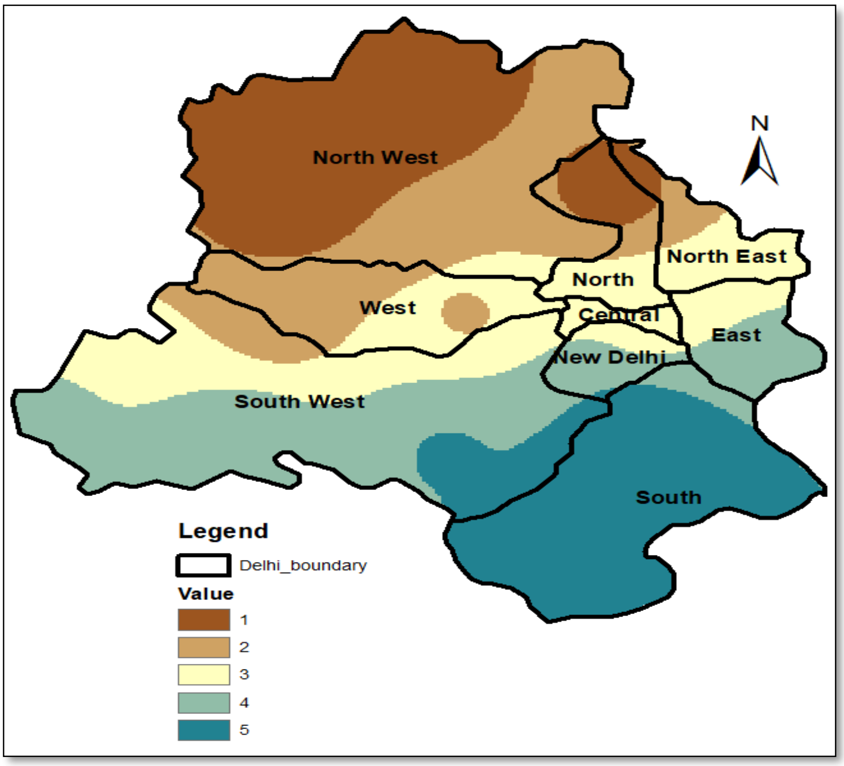


Figure 4.13 Hydraulic conductivity raw map Hydraulic conductivity map rated as per DRASTIC

IDW has been used to research and track the depth of ground water in Delhi as it changes over time. The depth data inputs take place on the India IWRS website. The graph below displays the variation in Delhi's groundwater depth during the last few years.

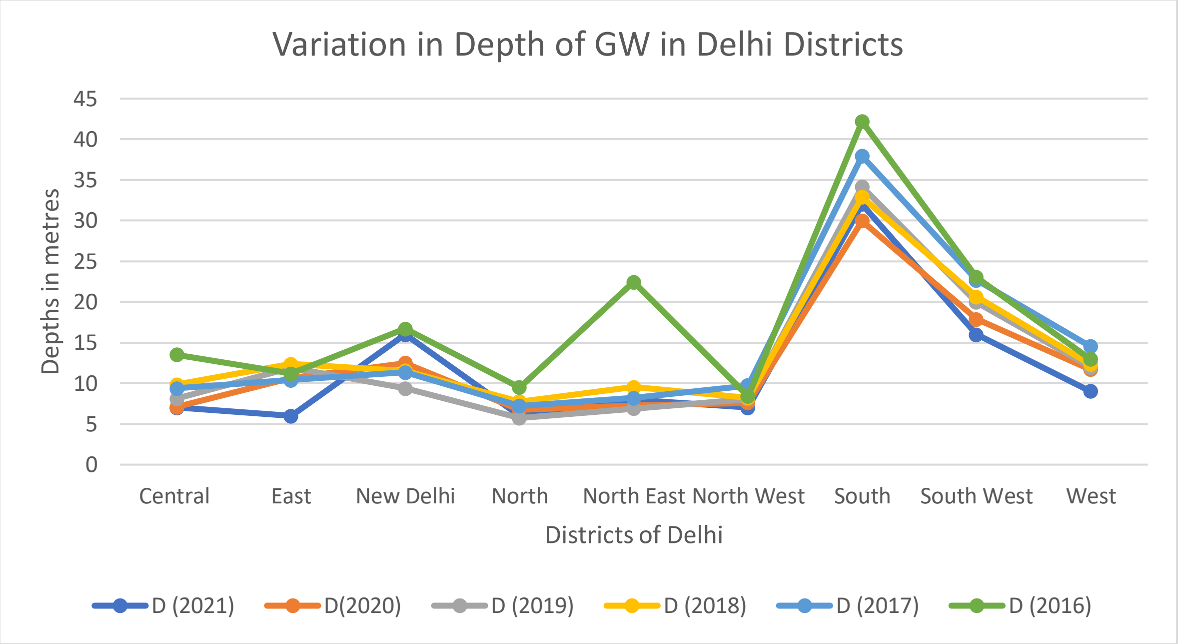


Figure 4.14 Annual variation in depth of ground water

The different maps are displayed here so that you can see how the depth levels of Delhi change over time. It demonstrates how ground water levels have decreased over time. The graph demonstrates how the levels vary significantly between the districts. In comparison to the area of North Delhi, the depth of the ground water is substantially greater in the south. The visual representation demonstrates that the green region has shrunk over time, i.e., ground water levels that were formerly considerably higher levels have fallen.

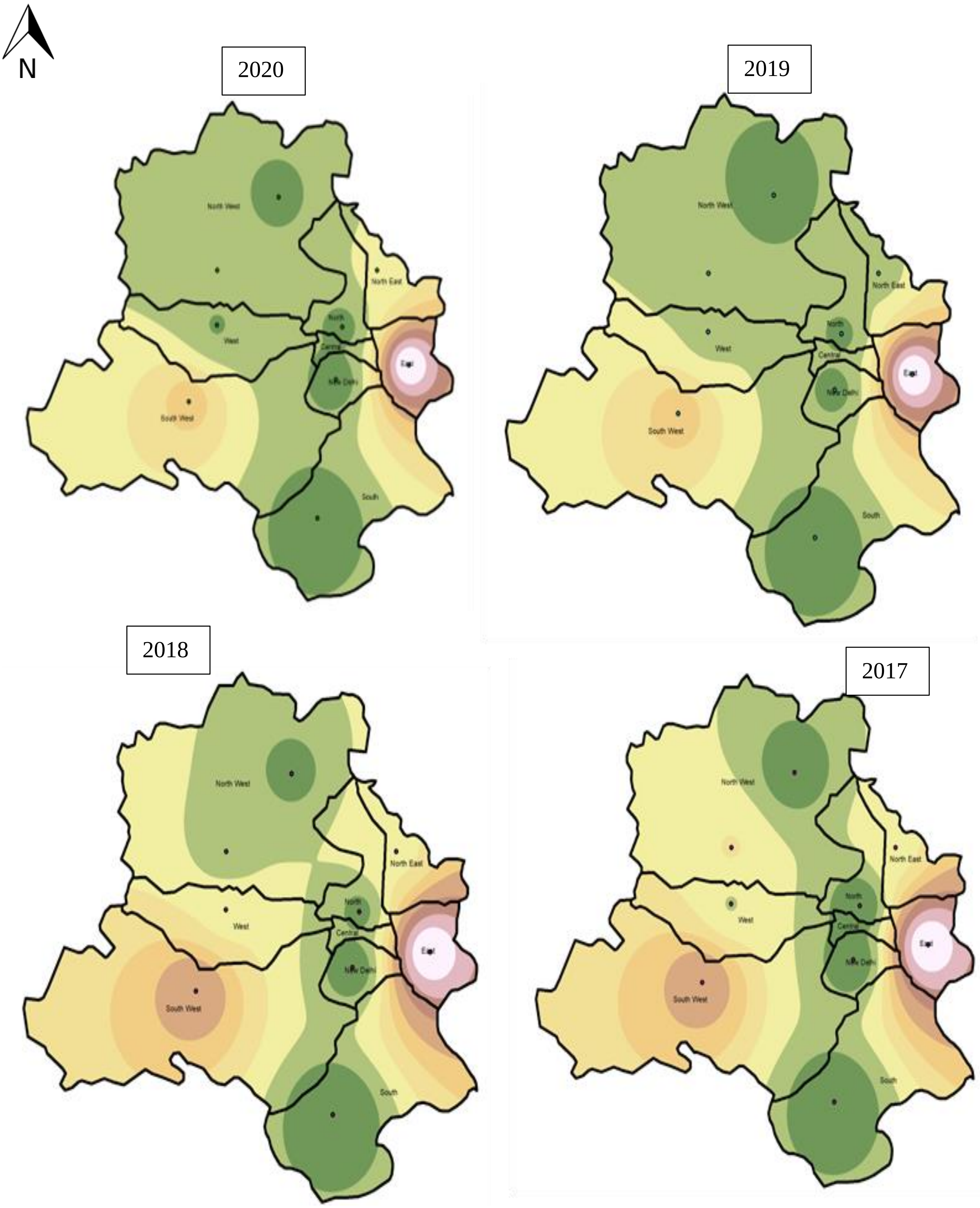


FIGURE 4.15: Annual changes in groundwater depth 2017,2018,2019,2020

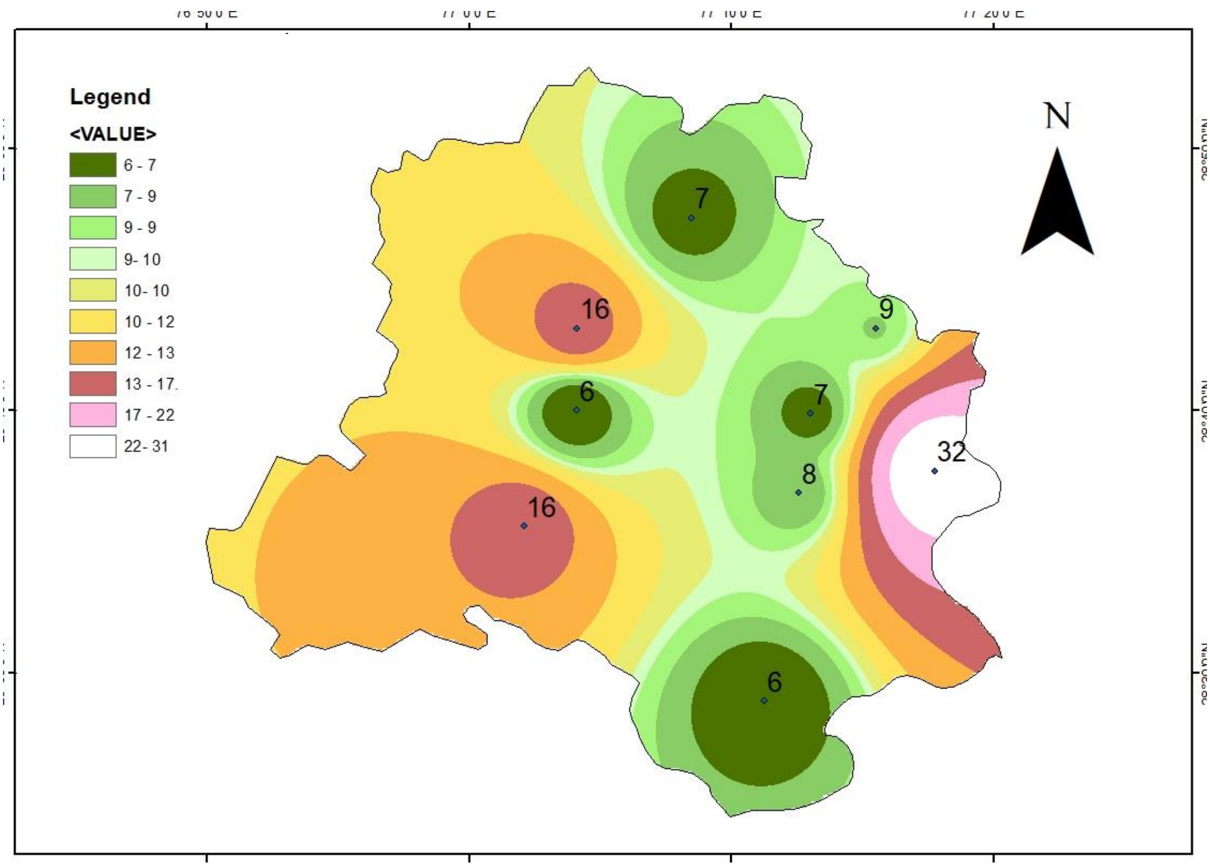


FIGURE 4.16 IDW of Annual changes in groundwater depth of 2021-22.

The table below displays the Vulnerability Index results while accounting for each study parameter. According to what was previously said, DRASTIC rates and weights each factor used to calculate the vulnerability index. Individual parameters are supplied in the approach both rated and unrated in accordance with DRASTIC standards to help the reader better comprehend the model phases being executed. The final result before classifying the index is shown in the image below. In locations where the number is higher, the ground water issue is severe.

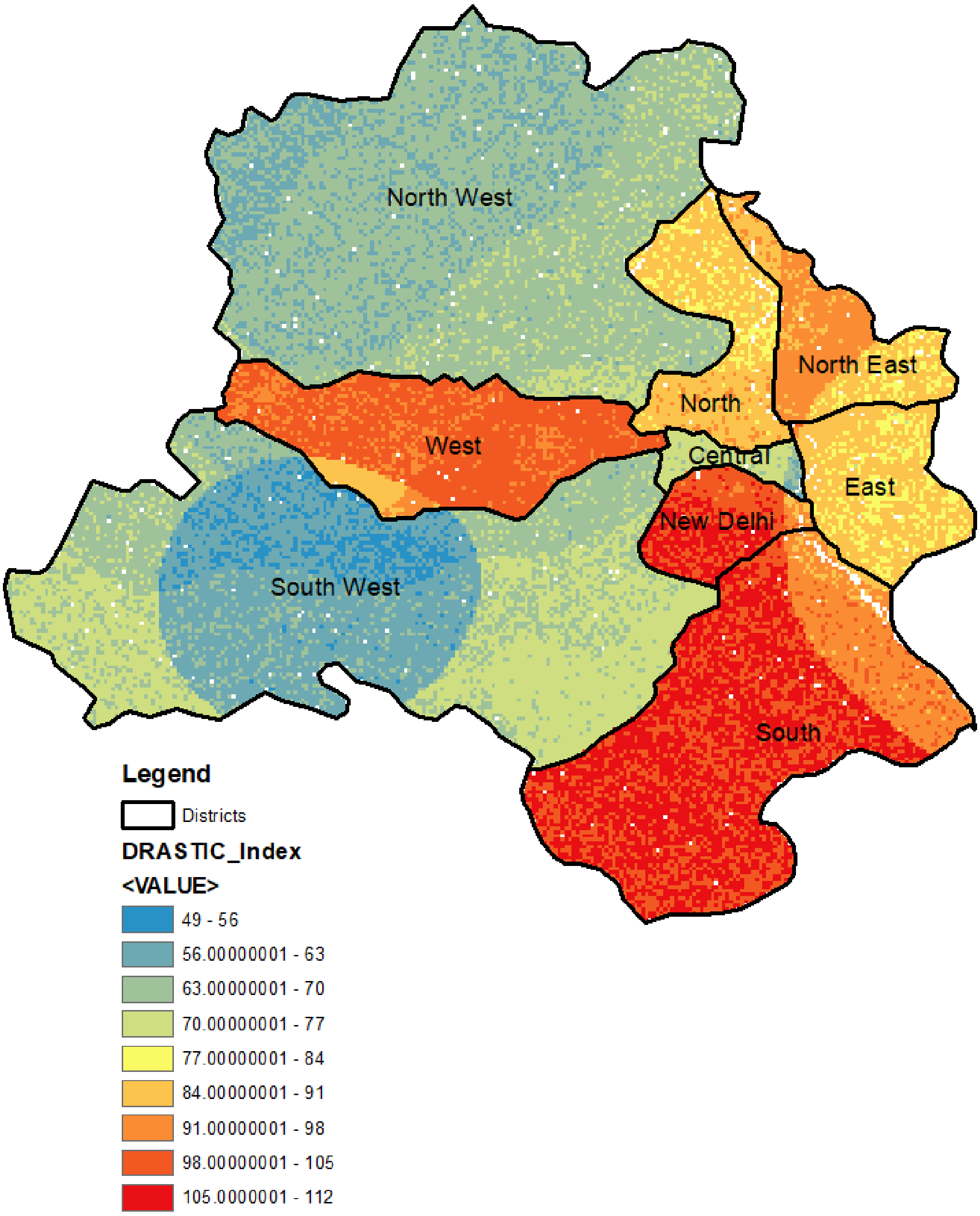
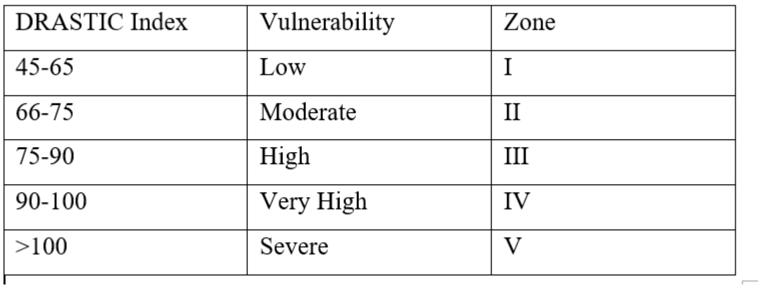


Figure 4.17: Results of the DRASTIC Index without classification

The aforementioned findings have been updated, and the region has been divided into five zones. The above-mentioned map has been modified as shown below based on quantile rating in ArcGIS. Based on the table below, vulnerability has been determined and classification has been made.

Table 4.2: Zone-level categorization using the Vulnerability Index



DRASTIC Index	Vulnerability	Zone
45-65	Low	I
66-75	Moderate	II
75-90	High	III
90-100	Very High	IV
>100	Severe	V

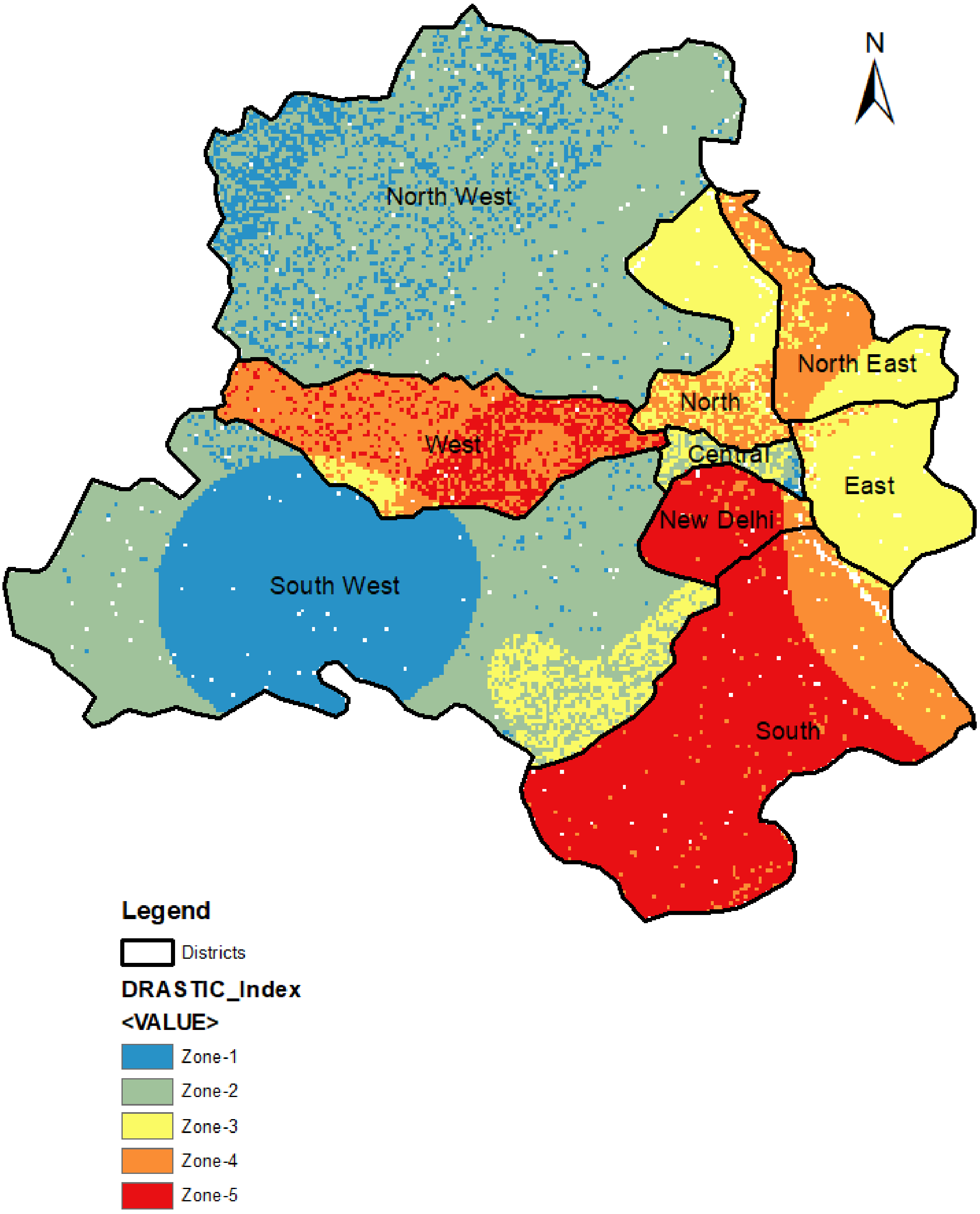
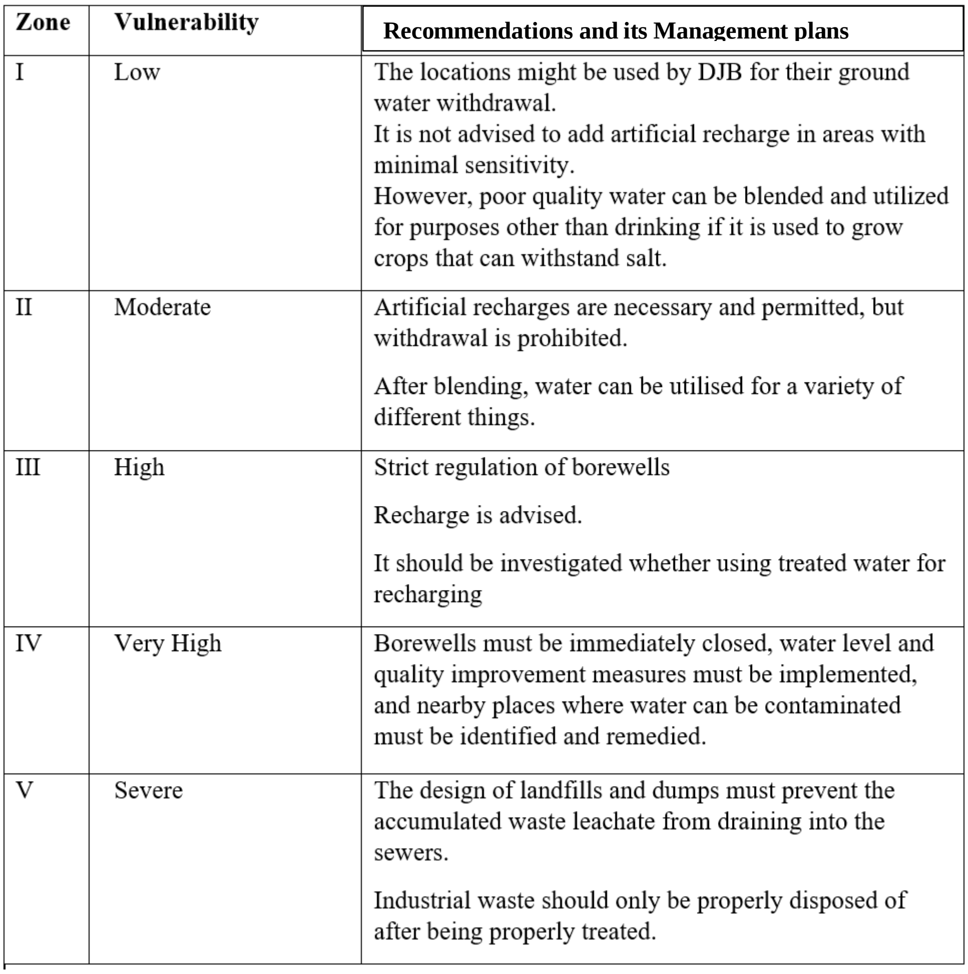


Figure 4.18: Zone-level categorization using the Vulnerability Index

Table 4.1: Zone-specific solution for resolving the issue



Zone	Vulnerability	Recommendations and its Management plans
I	Low	The locations might be used by DJB for their ground water withdrawal. It is not advised to add artificial recharge in areas with minimal sensitivity. However, poor quality water can be blended and utilized for purposes other than drinking if it is used to grow crops that can withstand salt.
II	Moderate	Artificial recharges are necessary and permitted, but withdrawal is prohibited. After blending, water can be utilised for a variety of different things.
III	High	Strict regulation of borewells Recharge is advised. It should be investigated whether using treated water for recharging
IV	Very High	Borewells must be immediately closed, water level and quality improvement measures must be implemented, and nearby places where water can be contaminated must be identified and remedied.
V	Severe	The design of landfills and dumps must prevent the accumulated waste leachate from draining into the sewers. Industrial waste should only be properly disposed of after being properly treated.

4.2 Policy and Technology Interventions suggested

The implementation of digital transformation in the fields of research, business, IT, and health has been discussed. An intervention that will be helpful in terms of data interpretation, technologies, and policy making is looking at water digitally. Individually, we must move quickly as a group based on the veracity of the information at hand if we are to transform the sustainability of our water conditions. When it comes to handling societal-level concerns, an integrated water management approach is beneficial. It is also less frequently discussed how to make the management process transparent.

Modern tracking technology, associated gear, and software are combined to create River Information Systems, which are intended to optimise traffic and shipping operations in inland navigation. The system intends to improve communication between different inland water transportation players. The system can be utilised to deliver real-time information on other ground water quality metrics to many engaged stakeholders in addition to providing information regarding real-time conditions including wind speed, hazard zones, fog, depth information, and route specifics to operators, etc.

The following image shows a few digital transformations that could be taken into account when creating or developing a policy or implementing any technology in the Indian context.

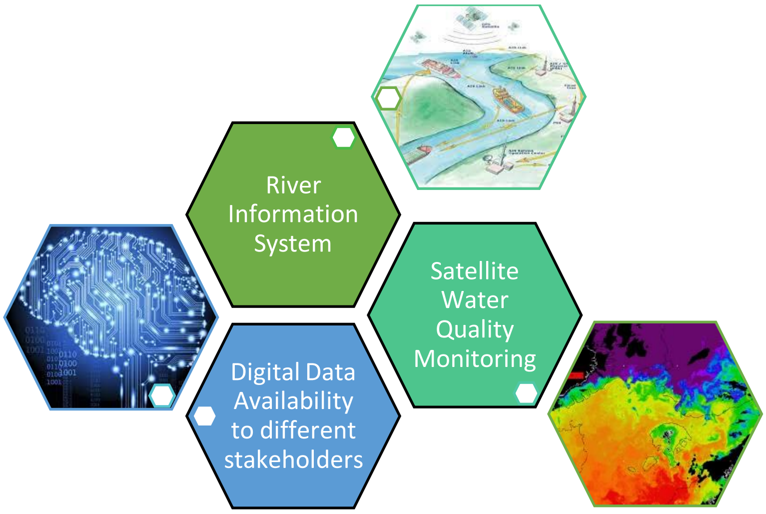


Figure 4.19: Digital transformations for policies for Governance inefficiencies in identification of the problem

4.2.1. Governance inefficiencies in identification of the problem

Digital transformations can be used to greatly improve the current governance system. Digital platform data outreach, which reaches stakeholders in various ways depending on the situation, is a significant step toward integrating technology into the process of formulating public policy.

The blind adoption of Nordic and other technology by Indian states is another issue that requires consideration. We are bringing capital investment technology to our country despite the fact that the terrain of various nations varies. These are not only ineffective, but they also waste money that may be put to better use in the near future.

4.2.2. OCEMS (Online continuous effluent monitoring system)

In 2018, the Central Pollution Control Board released updated instructions for OCEMS. We are able to track the water quality metrics in real time thanks to the OCEMS. When the initial CEMS system was deployed at Delhi's Indraprastha Thermal Power Plant in 2009, the concept of CEMS was first made public. All SPCB/PCC were given instructions by the CPCB in February 2014 to direct the installation of OCEMS in 17 categories of severely polluting companies. The CPCB has also issued a number of other directives for the same execution.

Despite these efforts, just a few states have the system installed, and those that do not maintain it. The systems will most likely sustain damage quickly. The management and upkeep of a central server where real-time data can be viewed are also lacking.

The first thing the nation needs is to instal the CEMS and to have a single server from which we can access the required data for each state whenever we want. Local regulations may be discussed later. The availability of data for future and urgent measures in case of any harmful pollution depends on the current quality of the water.

4.2.3. Use of satellites for water quality modelling and monitoring

By mounting devices on satellites and aircraft, it is possible to remotely sense and monitor water quality. There are programmes called data path finder that link to information that can be used to evaluate water quality and track changes in it. Measurements from satellite, aircraft, and in-situ sensors are used in the process to determine the water quality conditions. NASA created the system. Despite the fact that these software require prior adjustments and technical expertise, the assessment and process are considerably simpler and more accurate.

4.2.4. Based on the need, the form of data available to each stake holder shall be decided upon and made reachable.

A critical step towards better policy execution is to configure the demand supply gap and include technological interventions in the programmes. Existing regulations may also be changed in light of the data accessibility brought on by technology advancements. Information on water quality that is made available through various techniques is used in various ways. Information needs are ranked from a managerial or governance level down to the general public.

Different stakeholders with varying levels of involvement in the hierarchy will need different levels of data. An impact assessment consultant, for instance, must have a future prediction of the same data rather than all the information from the past and present.

4.2.5. Putting in place all the stakeholders with clearer incentive structures

All of the aforementioned parties involved in the water management process must have a clear understanding of their own goals in order for the policies that will be created for them to be effective.

4.2.6. Development of a model for each type of area or variety of structured industries and strict enforcements for water audits

The availability and accessibility of water in any place, whether it be an industrial area, a residential area, or an agricultural field, shall be studied using a model that is being built. This would make it possible to conduct a better area audit. Such a model can be applied to current regulations to determine the precise scenario of local water management.

Any industry must be equipped with the technologies stated in the process interventions based on the area's water consumption assessment in order to use less water for the same purpose. This analysis, intervention, and reduction procedure will enhance water management so that it is managed sustainably, i.e. without compromising with the demands of the future.

4.2.7. Looking at water security in a more integrated way while focusing on understanding the concept before putting it into the policies

Undeveloped notion known as "water security" is now mistaken for "water availability." Considering the idea as a comprehensive strategy for both accessibility and water availability. The lack of access to water affects a wide range of people in society, sometimes due to caste- and gender-based prejudices. Rather than focusing solely on the availability of water, policies should also address integrated water security.

Chapter 5.

Conclusion

Both the quality and quantity of ground water are being overexploited. It is perilous for humankind to deplete and contaminate the finite sources of our pure water. As can be observed from the study, Delhi's land use has literally altered due to the city's rapidly growing population and urbanization, which has had a significant impact on the ground water. For a city to develop, development is equally necessary, but it's also critical to consider smarter alternatives. The ground water of Delhi Region is highly dependent on its intrinsic characteristics of lithology with structures. GIS-based DRASTIC model evaluates the groundwater vulnerability and it has been proven accurately in this study area. DRASTIC vulnerability index value ranges from 49 to 112 and classified by five groups like Low(45-65), moderate(66-74), high(75-90) and very high vulnerable zone(90-100) and severe(>100) and mapped through GIS.

The first objective of the research is to study the cause-and-effect relationship for ground water contamination in Delhi where results showed greater will be the ground water depth leads to less vulnerability of aquifer whereas higher the hydraulic conductivity greater will be the vulnerability of the region. Second objective, to study the solute flow transport from dumpsites in Delhi using existing literature which states that Delhi Ridge is characterized by marginal alluvium helps in controlling groundwater situation with regime prediction. Eventually above two objectives helped in finding of third objective i.e vulnerability mapping of Ground water in Delhi using DRASTIC model method in GIS has shown with demonstration of different zones. Last objective is to come up with sustainable water management program for Delhi including capacity building techniques (based on the vulnerability index) of ground water management.

Present study reflects that groundwater pollution vulnerability patterns are the result of anthropogenic activities and hydrogeological setting of the study area. As spending money on large technologies and then realising the waste due to unsuitability has been prevalent in India, comprehensive studies like the National Aquifer Management Program must be done on a timely basis. To close the fundamental capital availability gap, funds used for fighting wars and other preventable problems will be invested in this area of study. To be more specific, it should be tightly enforced in Delhi that only treated wastewater flow into the sewers in order to prevent groundwater pollution along sewers. Drain lining must be done as well. Relevant state authorities should take the necessary precautions to protect groundwater quality, including properly locating and planning landfills, closely monitoring and randomly assessing water quality around industrial belts. Additionally, in locations with a lower water depth that is still increasing, rain water harvesting and artificial recharge procedures might be considered as fundamental remedies for dropping ground water levels.

Individual actions include following rules, maintaining the cleanliness of the areas that the government has already cleaned for us, harvesting rainwater to recharge the groundwater table, transforming the area into a greener space, and at the very least refraining from letting any more trees fall.

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ANNEXURES

ANNEXURE-I
SOURCES- CWGB REPORT 2020-2021

Table A.1.1 Water quality parameters of Delhi region.

S. No	Location	pH*	EC* in µS/cm at 25^0 C	CO_3	HCO_3	Cl*	SO_4	NO_3^*	F*	PO_4	Ca*	Mg*	Na*	K*	SiO_2	TH *as $CaCO_3$
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Asola Pz	8.04	731	0	232	156	27	15.00	0.30	<0.10	44	27	109	0.8	20	220
2	Auchandi Pz	8.42	4750	84	451	581	1024	12.47	0.64	<0.10	60	102	840	21	24	570
3	Bakoli	7.94	4850	0	293	1120	668	<0.20	0.80	<0.10	196	143	649	23	23	1080
4	Balbir Nagar DW	8.24	343	0	146	35	18	5.10	0.27	<0.10	44	5	29	1.2	22	130
5	Bankner Pz	7.74	3860	0	244	702	764	25.25	0.78	<0.10	220	88	424	146	27	911
6	Baprola DW	8.24	230	0	85	28	28	2.17	0.20	<0.10	16	25	5.7	0.4	23	130
7	Barwala Pz	7.30	8300	0	207	2410	630	19.32	0.58	<0.10	838	304	508	6.6	21	3143
8	Birla Mandir DW	8.23	670	0	195	106	66	3.49	0.37	<0.10	48	27	73	0.8	24	230
9	CBD Shahdara	7.78	6530	0	244	1588	902	8.01	0.70	<0.10	176	153	1058	19	21	1070
10	Chandni Chowk DW	8.21	835	0	207	198	27	31.04	0.25	<0.10	52	10	124	55	20	170
11	Chilla Regulator	8.00	762	0	244	149	8	3.03	0.06	<0.10	56	22	86	8.8	22	230
12	Delhi College Of Enginnerring	8.45	1225	60	244	149	171	1.63	0.92	<0.10	16	15	267	15.5	26	100
13	Dwarka S-16 (TP)	8.20	230	0	49	21	42	1.97	0.30	<0.10	28	10	3.1	0.4	21	110
14	Dwarka Sec-23 DDA Park	8.74	3180	144	744	532	35	8.36	0.92	<0.10	44	36	624	28	23	260
15	Dwarka Sec-5 DDA Park	8.60	978	48	293	113	50	4.87	0.86	<0.10	20	22	182	4.4	25	140
16	Gadaipur Pz	8.50	741	72	159	99	36	17.53	0.55	<0.10	20	19	147	0.80	21	130
17	Gazi Pur Crossing	8.05	1885	0	342	340	228	8.12	0.58	<0.10	92	78	238	1.0	24	500
18	Haiderpur Pz	8.17	688	0	195	106	66	6.00	0.44	<0.10	44	44	44.1	3.4	21	290
19	Hareoli Pz	8.56	3410	48	220	440	884	25.92	0.60	<0.10	48	146	507	10	25	721
20	Hiran Kudna DW	7.25	15420	0	171	4878	1117	31.04	0.92	<0.10	481	389	2463	58	23	2802
21	Humayu Tomb DW	7.95	2330	0	195	447	399	34.54	0.25	<0.10	96	49	367	1.5	28	440
22	India Gate Pz	8.32	2450	48	354	404	289	29.90	0.98	<0.10	36	41	462	9.5	22	260

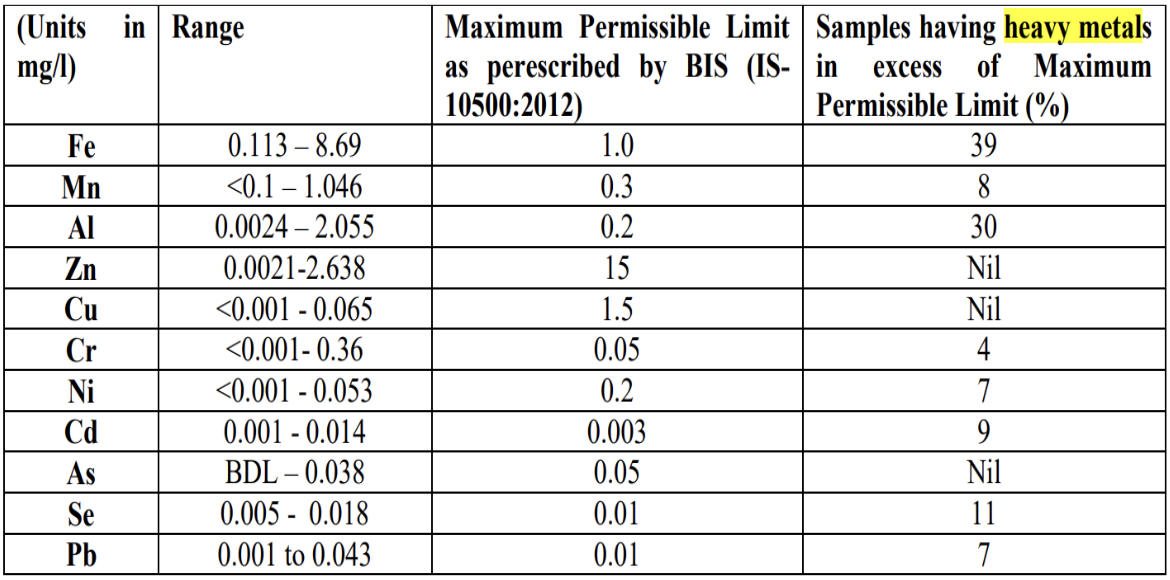
Table A.1.2 Water quality parameters of Delhi region.

S. No	Location	pH*	EC* in µS/cm at 25^0 C	CO_3	HCO_3	Cl^*	SO_4	NO_3^*	F^*	PO_4	Ca^*	Mg^*	Na*	K*	SiO_2	TH *as $CaCO_3$
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
23	Jagatput Pz 1	8.10	912	0	231	149	88	16.09	0.27	<0.10	64	34	86	60.8	21	250
24	Jamali Kamali DW	8.45	1450	84	292	291	5	10.21	0.42	<0.10	28	29	281	6.0	19	190
25	Janakpuri Pz	8.20	187	0	73	28	3.36	0.87	0.17	<0.10	20	12	2	0.1	29	100
26	Jaunti DW	8.60	6000	60	427	709	1551	12.84	0.94	<0.10	72	41	468	1353	23	350
27	Jharoda Kalan Pz	7.92	15270	0	220	4963	80	17.53	0.46	<0.10	521	584	1617	60	22	3703
28	Jheel Khoh DW	8.15	652	0	268	92	6.24	35	0.48	<0.10	44	22	88.7	0.1	16	200
29	Kanjhawala Pz	8.65	3390	120	696	510	206	29.04	0.66	<0.10	32	34	683	29	19	220
30	Kingsway Camp Police Ground Pz	8.45	630	36	122	120	48	0.41	0.84	<0.10	52	15	90	2.0	22	190
31	Lodhi Garden (D)	7.71	1472	0	122	283	136	136	0.25	<0.10	88	58	135	6.6	31	460
32	Mahabir Vansth.	7.94	1077	0	220	177	103	7.77	0.60	<0.10	60	29	143	5.2	27	230
33	Majara Dabas	8.17	219	0	98	21	0.96	2.01	<0.05	<0.10	28	4.86	1.0	1.1	6.62	110
34	Majnu Ka Tila DW	8.31	1362	24	268	177	108	81.00	0.58	<0.10	40	27	214	19	21	210
35	Mangolpur Pz	8.41	563	36	171	57	43	6.51	0.25	<0.10	48	17	65.2	2.3	25	190
36	Mayur Vihar B Block Ph II	8.29	504	0	146	57	74	2.12	0.32	<0.10	40	17	50.8	0.5	10	170
37	Najafgarh Town	8.27	212	0	98	14	12	2.48	<0.05	<0.10	32	7.29	2	1.1	5.67	110
38	Nizampur EW	7.62	25200	0	403	4254	7601	118	2.75	<0.10	416	671	4785	110	21	3803
39	Nizamuddin Bridge 2 Pz	8.26	961	0	207	206	16	41	0.44	<0.10	60	19	127	9.0	16	230
40	Ojwah Pz	8.14	5740	0	391	1503	378	50	0.76	<0.10	160	137	872	26	22	961
41	Palla Temple	8.35	663	60	98	85	49	1.24	0.42	<0.10	36	19	86	1.8	20	170
42	Palla Zero RD	8.25	1415	0	244	205	232	1.00	<0.05	<0.10	52	24	230	8.0	20	230
43	Peeragarhi DW	8.14	4770	0	488	1177	715	56	0.84	<0.10	200	231	647	6.0	19	1451
44	PUSA (NRL) Pz	7.88	2040	0	378	460	49	33	0.00	<0.10	88	83	217	14	29	560

Table A.1.3 Water quality parameters of Delhi region.

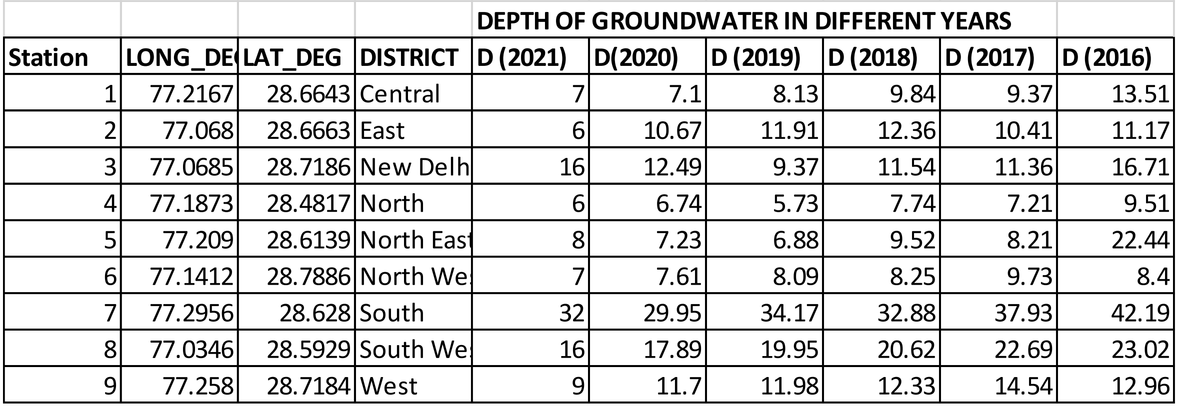
S. No	Location	pH*	EC* in µS/cm at 25^0 C	CO_3	HCO_3	Cl^*	SO_4	NO_3^*	F^*	PO_4	Ca^*	Mg^*	Na*	K*	SiO_2	TH *as $CaCO_3$
				mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
45	Rai Khera DW	8.04	8160	0	281	1474	1551	531	0.60	<0.10	240	389	737	443	26	2202
46	Rohini Sector 28	8.74	2270	48	134	142	819	20	0.50	<0.10	16	32	496	10	25	170
47	Safdarjung Tomb	8.26	1708	0	207	397	118	22	0.25	<0.10	64	58	213	13	35	400
48	Sainik Vihar (Pz)	8.14	9360	0	354	2830	376	19	0.76	<0.10	200	170	1590	36	24	1201
49	Sandesh Vihar Pz	8.16	4500	0	391	1021	490	4.45	0.70	<0.10	104	112	711	16	25	721
50	Sanjay Van Pz	8.28	1512	0	488	99	225	1.25	3.40	<0.10	36	27	268	10	18	200
51	Sectpr - 5 Rohini (Pz) Rithala	8.70	1873	72	403	199	195	8.99	1.62	<0.10	20	27	358	9.0	20	160
52	Sector -1 Rohini (Pz)	8.25	2810	0	244	617	344	32	0.64	<0.10	72	146	316	0.5	25	781
53	Shekhwanti Line Pz	7.90	1985	0	293	425	133	35	<0.05	<0.10	84	44	281	13	30	390
54	Shram Shakti Bhawan	8.47	1586	48	208	248	145	62	0.42	<0.10	40	61	201	16	28	350
55	Singhola Pz	8.04	3630	0	244	588	807	91	0.64	<0.10	104	156	483	3.0	20	900
56	Sultanpur IMS Pz	8.74	626	48	220	43	35	10.45	<0.05	<0.10	12	15	128	2.0	34	90
57	Tagore Garden Pz	7.95	11440	0	183	1850	4323	44	0.54	<0.10	489	355	2105	50	27	2682
58	Tiggipur Deep Pz	8.41	601	24	122	78	66	1.03	0.60	<0.10	36	12	83.7	2.4	25	140
59	Tikri Kalan	7.84	8510	0	268	1481	1852	53	1.55	<0.10	361	530	542	32	24	3082
60	Vikaspuri Pz	8.62	1175	72	232	113	23	126	1.55	<0.10	24	22	206	9.0	24	150
61	Laxmi Nagar Bank Encl Pz	8.17	1092	0	256	199	36	33	<0.05	<0.10	48	17	168	3.2	20	190
62	Rithala Village, Rohini Sec-1	8.57	2960	36	317	503	470	7.27	2.4	<0.10	32	107	458	19	20	520
63	Gujarat Vihar, Preet Vihar	8.33	1331	24	305	177	126	8.31	<0.05	<0.10	40	36	198	5.0	25	250
64	Lalitha Park, Laxmi Nagar	8.08	1347	0	281	205	156	33	<0.05	<0.10	64	36	181	12	18	310

Table A.2.1 ISO-10500, Water quality parameters of Delhi region.



(Units in mg/l)	Range	Maximum Permissible Limit as perescribed by BIS (IS-10500:2012)	Samples having heavy metals in excess of Maximum Permissible Limit (%)
Fe	0.113 – 8.69	1.0	39
Mn	<0.1 – 1.046	0.3	8
Al	0.0024 – 2.055	0.2	30
Zn	0.0021-2.638	15	Nil
Cu	<0.001 - 0.065	1.5	Nil
Cr	<0.001- 0.36	0.05	4
Ni	<0.001 - 0.053	0.2	7
Cd	0.001 - 0.014	0.003	9
As	BDL – 0.038	0.05	Nil
Se	0.005 - 0.018	0.01	11
Pb	0.001 to 0.043	0.01	7

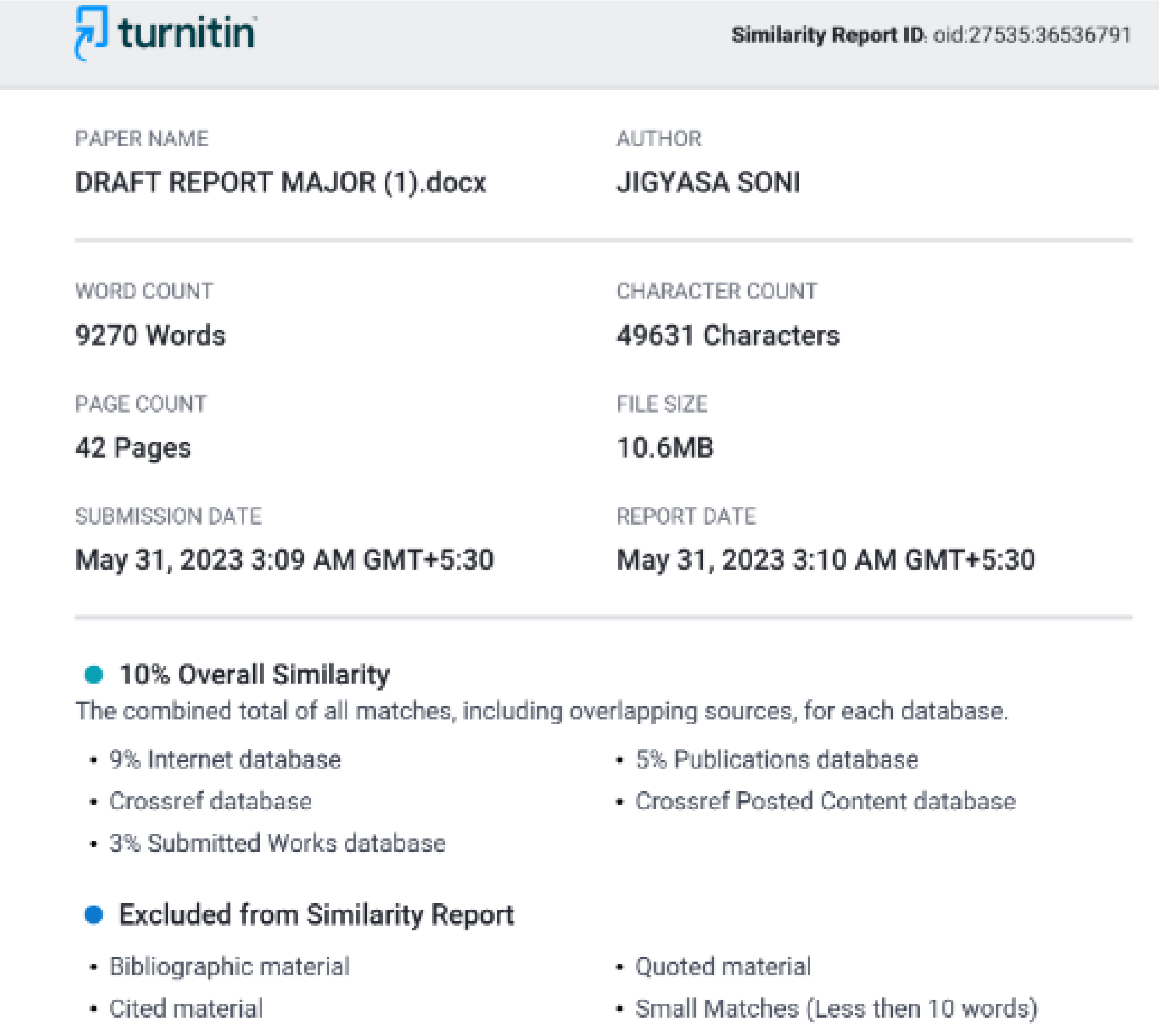
Table A.2.2 Ground water depth of Delhi region.



				DEPTH OF GROUNDWATER IN DIFFERENT YEARS					
Station	**LONG_DE**	**LAT_DEG**	**DISTRICT**	**D (2021)**	**D(2020)**	**D (2019)**	**D (2018)**	**D (2017)**	**D (2016)**
1	77.2167	28.6643	Central	7	7.1	8.13	9.84	9.37	13.51
2	77.068	28.6663	East	6	10.67	11.91	12.36	10.41	11.17
3	77.0685	28.7186	New Delh	16	12.49	9.37	11.54	11.36	16.71
4	77.1873	28.4817	North	6	6.74	5.73	7.74	7.21	9.51
5	77.209	28.6139	North Eas	8	7.23	6.88	9.52	8.21	22.44
6	77.1412	28.7886	North We	7	7.61	8.09	8.25	9.73	8.4
7	77.2956	28.628	South	32	29.95	34.17	32.88	37.93	42.19
8	77.0346	28.5929	South We	16	17.89	19.95	20.62	22.69	23.02
9	77.258	28.7184	West	9	11.7	11.98	12.33	14.54	12.96

ANNEXURE III

.



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