"ASSESSMENT AND INDEXING OF GROUNDWATER QUALITY OF DELHI, INDIA USING GIS"

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF DEGREE
OF

MASTER OF TECHNOLOGY
IN
ENVIRONMENTAL ENGINEERING

Submitted by:

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CANDIDATE'S DECLARATION

I, AYUSHI RAGHAV, Roll No. 2K18/ENE/05 student of M.Tech (Environmental Engineering), hereby declare that the project Dissertation titled **"ASSESSMENT AND INDEXING OF GROUNDWATER QUALITY OF DELHI, INDIA USING GIS"** which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, 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 AYUSHI RAGHAV

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CERTIFICATE

I hereby certify that the Project Dissertation titled **"ASSESSMENT AND INDEXING OF GROUNDWATER QUALITY OF DELHI, INDIA USING GIS"** which is submitted by Ayushi Raghav, Roll No. 2K18/ENE/05 Department of Environmental Engineering, Delhi Technological University,Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **Prof.S.K.Singh**

Date: (SUPERVISOR)

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ABSTRACT

Ground water is a fundamental and crucial segment of our life supportive network. The ground water assets are being used for drinking, water system and mechanical purposes. There is developing worry on decaying of ground water quality due to geogenic and anthropogenic activities. The present study evaluates the groundwater quality of National Capital Territory (NCT) Delhi with respect to drinking and irrigation purpose using Geographic Information System (GIS). The Water Quality Index (WQI) of the groundwater for drinking purposed is also calculated in this work. The data used in this work was collected from CGWB WRIS for the years 2010 and 2015 for twenty-eight locations in the study area. The drinking water quality has been defined using the parameters such as pH, total alkalinity, total hardness, calcium content, nitrate content etc. while irrigation water quality has been defined using the parameters as sodium absorption ratio, salinity hazard , permeability index etc. Spatial distribution maps of these parameter have been generated using QGIS (version 3.10.2). It was observed that in majority of study area the overall concentration of pH, magnesium, potassium, sodium, chloride, fluoride and sulphate in groundwater had been increased over the span of five years from 2010 to 2015.While overall concentration of total hardness, total alkalinity, nitrate and calcium in groundwater had been decreased over the span of five years from 2010 to 2015. Irrigation water quality of majority of the areas was lying under “excellent” to “good” quality category. About 67.8% of the area in 2010 and 78.6% of the area in 2015 under the study comes under “poor” to “unsuitable for drinking category” as revealed by the WQI studies. It can be concluded that overall quality of groundwater of Delhi had been deteriorated from 2010 to 2015. The reasons for this might include increase in population,

over-exploitation of groundwater resources, urbanization and industrialization on large scale.

Keywords: Groundwater quality, Quantum Geographic Information System (QGIS), Water quality index (WQI), NCT Delhi and Spatial distribution.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Water is an essential commodity for the existence of life on planet Earth. It is used for multiple benefits like for drinking, washing, agricultural and industrial use. Without water one cannot imagine survival on this planet. Total volume of water present on Earth is estimated to be 1.386 billion cubic km. The distribution of water among different forms is uneven with about 97.5% of total volume being salty in nature mainly found in marginal seas and oceans, saline groundwater and water from the saline closed lakes . The average salinity is 4.5% approximately. The remaining 2.5% of the total volume of water is fresh water, mainly existing in the form of snow, ice caps and glaciers, groundwater and soil moisture. Only about 1% of this fresh water is available for use.

The water resources are considered as an important asset of a country. The main source of water resources in India is through various forms of precipitation. It annually receives about 4000 cubic km of precipitation. The precipitation is not uniformly distributed over the entire land area and it varies from less than few mm in Rajasthan to more than 2500 mm in Assam. Of all the precipitation received by the land, mountains and forests, some is evaporated back into the atmosphere and some is percolated into the ground. The remaining that flows into the river is less than 50% of the total precipitation received. The total annual flow in rivers is estimated to be 1869 cubic km. The total utilizable water resource is estimated to be 1123 cubic km/year out of which 690 cubic km/year is contributed by river flow and 433 cubic km/year is contributed by groundwater.

1.2 GROUNDWATER POLLUTION IN INDIA

Groundwater is an essential source of water in India. The irrigation sector largely depends on the groundwater for their supply and accounting for 89% of the groundwater used. The domestic sector uses about 9% of the groundwater, industries uses about 2% of the groundwater. 50% of the urban requirements and 85% of the rural requirements are satisfied by the groundwater (Suhag,2016).

Groundwater is better known as universal solvent. The chemical composition of water is decided by the minerals present in the soils and rocks through which it flows. The degree of contamination of the groundwater depends largely on the formation and geo-chemistry of the soil through which it flows before reaching the aquifers (Zuane, 1990). It is not possible to accurately estimate the degree of contamination of the groundwater as it flows beneath the surface. Once the groundwater gets contaminated, it takes longer time to regain its original quality. Therefore, it is important to regularly monitor the quality of groundwater and to develop an effective management plan to protect it.

The water quality of any specified source like groundwater can be assessed using three parameters namely chemical, biological and physical (Ketata Mouna, et al., 2011). The observed values of these parameters, if crosses the defined limit set by organization like WHO or BIS, then the water is said to be harmful for human health. Therefore, the term

Water quality index (WQI) has been introduced to describe the water quality in one of the most effective way. Hortan(1965) had developed the Water Quality Index in the United States by selecting 10 most commom water quality parameters namely pH, chloride, hardness, total alkalinity, electrical conductance etc (Tyagi et al., 2013).

Geographic Information System (GIS) is a tool used widely on different platforms for capturing, storing, analyzing and presenting the geographical data. The first GIS was developed in 1960 by Federal Department of Forestry and Rural Development. By the end of 20th century, various applications of GIS have been developed. Many software like QGIS, ArcGIS etc have been developed and are in public domain to cover a wide range of application fields around the globe as mapping of natural hazard risk, in fields of agriculture, forestry.

1.3 PROBLEM AND OBJECTIVES

The groundwater quality of India is deteriorating at a rapid scale. The extraction of groundwater resource for irrigation,domestic and other uses is increasing as scarcity of surface water has increased. But due to over exploitation of groundwater resources the water table depth has lowered to several meters, mainly in states like Punjab, Haryana and Rajasthan. To increase the yield of the crops, fertilizers are extensively used. These fertilizers find their way to the surface water and some fertilizers get percolated into the deep groundwater, thus making it polluted. Groundwater pollution as compared to the surface water pollution is difficult to be monitored as they are not easily accessible. The various chemical of fertilizers like nitrate, potassium, magnesium, chloride etc when found in larger amount than the defined limit pollute the groundwater.

In this study, an attempt has been made to study the groundwater quality parameters of National Capital Territory (NCT) Delhi. NCT Delhi is the eight largest metropolis in the world as per 2011 census with a population of about 167.87 lacs. About 81 % of rainfall is received during a spell of 3 months from July to September. The water requirement for the rest of the year is mainly dependent on the groundwater. Due to variability in rainfall pattern in the city, the natural groundwater recharge gets affected. The water demand in NCT Delhi is increasing at rapid pace mainly due to increasing urbanization. Available surface water is not sufficient in meeting the needs of the city and hence groundwater plays an important role in fulfilling the water demands.

The groundwater of the city is mainly brackish to saline at deeper level in all aquifers. Over the last few decades, there has been indiscriminate use of groundwater resources due to increasing population, urbanization and industrialization. This over-exploitation of groundwater resources is leading to quality issues and decline in water levels. Groundwater is continuously getting polluted due to the disposal of untreated sewage directly into the natural drains.

The pace of rapid urbanization and industrialization, clubbed with irrigation needs, require groundwater resource planning and monitoring in the wider context of regional scale. This type of plan requires a systematic study to evaluate the spatial distribution of water quality so that any approach could be implemented in the area of study. Thus, in order to serve the need of water for its various uses, it is necessary to take preventive measures to ensure the water resource sustainability.

Objectives

1. To study and compare the groundwater quality for drinking purpose based on various parameters using the data collected from CGWB for the years 2010 and 2015.
2. To study and compare the suitability of groundwater for the irrigation purpose indirectly based on the data collected from CGWB for the years 2010 and 2015.
3. To generate thematic maps of spatial distribution of water quality parameters and indices using Geographical Information System for drinking and irrigation purposes.
4. To assess the Water Quality Index (WQI) of the groundwater for drinking purpose for the years 2010 and 2015 and generate a thematic map using Geographical Information system and compare the results.

CHAPTER 2

REVIEW OF LITERATURE

2.1 PHYSICO-CHEMICAL PROPERTIES OF WATER

Access to safe drinking water is an internationally accepted human right (World Health Organization (WHO) 2004) . Maintaining the quality of drinking water supplies has become an area of concerns for many countries. Surface water pollution has increased the pressure on groundwater resource for the demand for irrigation, drinking and industrial purposes. The chemical quality of groundwater can also affects the composition of the rocks and soils through which it flows.

Rao,N.S *et al*. (2011) had carried out the chemical characteristics and assessment of groundwater quality in Varaha River Basin, Visakhapatnam. Thirty water samples were collected from open dug wells from the study area. These samples were analyzed for total alkalinity, calcium, bicarbonate, sodium, potassium, chloride, total hardness, sulphate, nitrate and fluoride with the help of standard water quality methods and comparing the observed values with the limits defined by WHO and BIS. The evaluation of chemical characteristics and suitability of groundwater quality was done for irrigation, drinking and industrial purposes. The groundwater quality is characterized by the pH values ranging between 7.0-8.2, mostly brackish and very hard in the study area making it unfit for drinking .

Li,P. et al. (2012) assessed the groundwater quality for irrigation purposes in Pengyang County, China. Seventy Four samples were collected from during August 2007 out of which 16 were spring water samples and the remaining 58 samples were collected from the hand pumping wells. The samples were analyzed for 24 variables including pH, temperature, TDS, COD, major ions like sodium , calcium, chloride etc. 56.76 % of samples were of excellent quality and 41.89% of samples were of good quality. Thus, it indicate that the groundwater is suitable for the irrigation purpose, except for the few samples located in the north, lying in the marginal category .

Bhuiyan,M.A.H et al. (2016) conducted a study on assessment of groundwater quality of Lakshimpur district of Bangladesh with the help of water quality indices, geostatistical methods and multivariate analysis. A total of 70 groundwater samples had been collected from wells. The water quality index values were calculated using International Standards and BMAC values for the determination of groundwater quality for drinking purposes. The water quality index states that 50% of samples lie in good quality zone. Ordinary Kriging (OK) model is applied in this study. The OK interpolation techniques were applied to develop spatial distribution maps of groundwater data set for each groundwater pollution index. These maps provide a visual tool which is helpful for researchers and policy makers to predict the future extent of pollution .

Chopra and Krishan (2014) studied the groundwater quality of the entire Punjab state. The samples were collected using standardized methodology during 2009-14. During this period medium groundwater observation wells were being installed in the state under World bank aided Hydrology project phase II. Groundwater quality map were prepared using Electrical conductivity (EC) and Residual Sodium Carbonate (RSC) of samples collected. The results observed that groundwater quality between the depth of 45 and 60 metres is said to be fit in

53% well, marginal in 22% and unfit in 25% of wells. These were categorized on the basis of EC and RSC .

Longe and Balogun (2010) examined the groundwater contamination near a landfill site of Lagos state, Nigeria. Water quality parameters of leachate and groundwater were analyzed. It was found that the mean concentrations of the samples parameters conform to the WHO potable water standards and the Nigerian Standard for Drinking Water Quality except nitrate and phosphate. The results showed that the impacts of the landfill operation were insignificant on the groundwater resources .

2.2 WATER QUALITY INDEX

Dwivedi and Pathak(2007) defined the water quality index as a rating reflecting the combined influence of number of individual parameters of water quality on overall quality of water. The water quality index is a rating represented in terms of a value which shows the cumulative effect of different parameters describing the quality of water (Ramakrishnaiah et al., 2009).

Horton developed the first WQI model in 1965 to calculate the quality index of water. The criteria used for development of the WQI were-

i. Limited number of water quality parameters was selected to evaluate the index.
ii. Significant variables of the study area were included.
iii. Only those Parameters were included whose reliable data were available.

The WQI model developed by Horton (1965) included ten parameters which were commonly measured water quality parameters such as pH, DO, EC, coliforms ,alkalinity and chloride. These parameters were assigned index weight ranging from 1 to 4.

Wu et al. (2018) carried out a study on assessing river water quality using water quality index in Lake Taihu Basin, China. WQI was evaluated to assess the quality of water and its spatial variations in the river. Ninety six sampling locations were selected for the collection of data of 15 parameters namely river surface temperature, pH, DO, TN, nitrate, nitrite, electrical conductivity, turbidity etc. Each parameter was assigned a weight based on its effect on human health. WQI values of the sites were calculated on a seasonal basis and then mean was taken as a final WQI value. The overall water quality in all four seasons was classified as “moderate”.

Balan et al. (2012) aimed to assess the groundwater quality in Chennai city with the help of water quality index. Nine samples were collected from nine locations. A total of nine parameters such as TDS,pH, total hardness, turbidity, calcium, magnesium, sulphate, chlorides and nitrates. The results showed that the water quality index of the groundwater is good and fit for human consumption.

Boah et al. (2015) studied the Vea Dam in upper east region of Ghana to calculate the water quality index to assess suitability for drinking purposes. Samples were analyzed for ten parameters namely pH, TDS, electrical conductivity, total hardness, sulphates, nitrates, chlorides, DO, BOD and calcium. The water quality index was calculated using the weighted arithmetic index method . The results show that WQI was 54.21 and the water quality was found to be of poor quality.

Shah and Joshi (2017) developed water quality index along the Sabarmati river basin, Gujarat. During this study six parameters were selected namely pH, DO, BOD, Electrical conductivity, nitrate-nitrogen and total coliform. Weighted arithmetic water quality index was used here. It was found that the quality decreases as water of river flows from rural to urban area.

2.3 GEOGRAPHIC INFORMATION SYSTEM (GIS)

Geographic Information System (GIS) has been extensively used for understanding and working with problems of water and its resource which includes management of resources, representation of spatial variation of water quality parameters. GIs enables one to perform modeling and allows generating information across a wide range from local to global level that can contribute in management of resources.

Sadat-Noori et al. (2014) analyzed the groundwater quality of Saveh-Nobaran, Iran. This aquifer in Iran is considered as a major source of drinking and irrigation. The groundwater quality was assessed with the combined use of water quality index and GIS. Total fifty eight samples were collected and analyzed for pH, EC, TDS, chloride, sulphate, total hardness, magnesium, sodium, potassium, and bicarbonate. With the help of GIS, spatial distribution maps of these parameters were created using kriging method. Results showed that on the basis of WQI, 65% of samples fall within poor, very poor and suitable for drinking.

Gnanachandrasamy et al. (2015) aimed to evaluate the groundwater quality of Nagapattinam district, Tamil Nadu. The samples were analyzed for physio-chemical parameters such as pH, temperature, salinity, sodium, calcium, potassium, magnesium, chloride, bicarbonate and sulphate. ArcGIs 9.3 software was used to create thematic maps of various parameters and of the final groundwater quality map. Inverse distance weighting (IDW) interpolation method was used to obtain the spatial distribution of parameters of groundwater quality.

Adhikary et al. (2012) evaluated the quality of groundwater in a peri-urban area of Delhi, India. The parameters analyzed were EC, Sodium Adsorption ratio (SAR), TDS, nitrate, chloride, bicarbonate, hardness and magnesium/calcium ratio. The thematic maps were prepared using ArcGIS 9.3 software. These maps showed the spatial distribution of physio-chemical parameters representing the groundwater quality in terms of suitability for drinking and irrigation purpose.

Shabbir and Ahmad (2015) studied the groundwater quality of Rawalpindi and Islamabad, Pakistan for drinking and agricultural purposes. Twenty-two samples were collected from the open wells and bore wells. These samples were analyzed for different physio-chemical variables such as pH, Total alkalinity, TDS, nitrate, sulphate, bicarbonate, zinc, lead etc. Water quality index was calculated for the overall groundwater quality. ArcGIS (version 10.0) software was used for the assessment of groundwater quality in terms of spatial distribution mapping for different physio-chemical variables. The results showed the effectiveness of GIS as a tool for creating thematic maps representing the spatial distribution.

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the materials and method adopted to achieve the objectives of the study. It includes description of the study area in terms of its geography, rainfall and climate pattern and type and availability of water resources. It also explains the software used for the creation of thematic maps for drinking and irrigation purpose and the estimation of water quality index with respect to BIS guidelines for drinking purpose. The various parameters used for evaluating drinking and irrigation water quality are defined under relevant headings/ sub-headings.

3.1 DESCRIPTION OF STUDY AREA

3.1.1 Geography

Delhi, officially known as National Capital Territory of Delhi (NCT), is a union territory and a city covering an area of 1483 sq.km , of which 700 sq. km area is urban and 783 sq. km is rural area. It lies from 28º24’15” to 28º53’00” N latitude and from 76º50’24” to 77º20’30” E longitudes. The Delhi city has been divided earlier into nine districts namely New Delhi, North Delhi, North west Delhi, West Delhi, South west Delhi, South Delhi, Central Delhi , North East Delhi and East Delhi. In September 2012, two new districts namely South east Delhi and Shahdara were added. Area wise North West Delhi is the largest district and Central Delhi is the smallest. The total population of NCT Delhi is 167.87 lacs with a density of 11297 persons per sq.km as per census 2011.

This region is a part of Indo-Gangetic Alluvial Plains. It is surrounded by Haryana state on northern, western and southern sides and by Uttar Pradesh state in east .Delhi ridge and the Yamuna flood plains are two important features of Delhi. Yamuna is the only major river that flows through Delhi. The Delhi ridge originates from the Aravalli range in the south and encircles the north-west, north-east and western parts of the city.

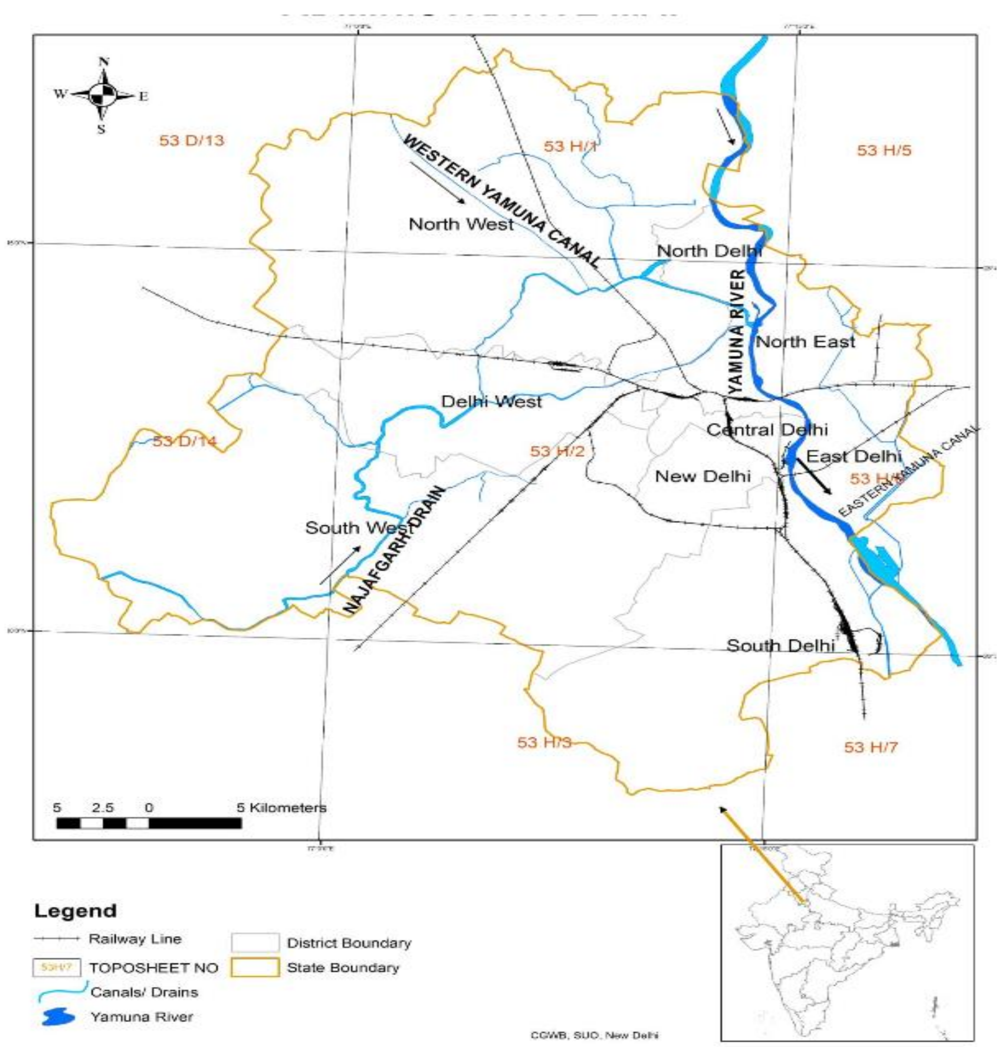

Fig 3.1: Administrative Map of National Capital Territory Delhi

3.1.2 Climate and Rainfall

Delhi lies in the Northern Plains of Indian Subcontinent. The climate of Delhi varies between humid subtropical to semi-arid with long and hot summers and cold winters. The climate of the city is greatly influenced by Thar Desert and Himalayas. Winter season begins in early November and extends up to the beginning of March, with January being the coldest month. The mean daily maximum and minimum temperature in the month of January is 21.3ºC and 7.3ºC respectively. Western disturbances cause occasional cold waves in the winter months while passing across North India. The city experiences summer from middle or ends of March and continues up to end of June, with May and June being the hottest month. From April month hot winds known as 'loo' blows and makes the weather unpleasant.. It also experiences monsoon from June end to September. Humidity is high during monsoon season. The average annual humidity is 54%. Delhi temperatures ranges from 2º to 47º C with mean of 29º C

The normal annual rainfall in the city is approximately 611.80 mm. The rainfall in the city increases from southwest to the northeast. About 81% of the total rainfall in a year is received during July, August and September, commonly known as monsoon months. August is considered to be wettest month of Delhi. Rest of the rainfall is received in form of thunderstorm rain before and after the monsoon months and in form of winter rain. Rainfall in Delhi is highly variable and thus in turn it affects the natural groundwater recharge from year to year.

3.1.3 Water Resources

Yamuna is the only major river that flows through the city of Delhi. It flows through the eastern part of the Delhi region covering 5 districts namely North, North west, North East, South and Central districts. This river plays an important role in groundwater system of the city. Yamuna flood plains are younger alluvial deposits. Yamuna River, upper Ganga canal and Western Jamuna canal are water sources for Delhi. Approximately 446 tube wells are constructed in Yamuna bed to meet the city's water requirement.

The NCT Delhi can broadly be divided into seven drainages basins which ultimately discharge into the River Yamuna. They are- (i) The Najafgarh Drain, (ii) Supplementary Drain, (iii) Wild life sanctuary area, (iv) Bawana Drain (v) Barapullah Drain, (vi) Drainage of Shahdara area and (vii) other drains directly falling into the river Yamuna on right bank.

3.2 ASSESSMENT OF GROUNDWATER QUALITY

The groundwater sources are considered to be one of the major sources of drinking and irrigation water. Due to urbanization and industrialization, groundwater is extensively used to meet the needs. Farmers are using fertilizers, pesticides and insecticides in differentially to boost their yields. These chemicals find their way to the groundwater and thus make it polluted. Apart from these chemicals, sewage disposal into the natural drains also pollute the groundwater. Hence it has become necessary to study the physico-chemical properties of groundwater to find out its suitability for drinking and irrigation use.

3.2.1 Collection of Data

The data used in this study is taken from the Central Ground Water Board (CGWB) Water Resource Information System (WRIS) of India. The data is collected for the year 2010 and 2015. Groundwater quality of nine districts of Delhi has been monitored here using 11 physico-chemical properties of water. In total, the groundwater data were analyzed for 28 stations spread over the nine districts of Delhi as reported in Table 3.1 and the geographical details of the locations are given in table A1 . The GPS locations of the sampling stations were recorded for mapping spatial distribution of the water quality parameters through QGIS (version 3.10.2) software.

Table 3.1 Details of the Monitoring Stations

S.No	Stations	S.No	Stations
1	Akshardham Temple	15	Barwala
2	Chilla Regulator	16	Bawana
3	Nizamuddin Bridge-2	17	Delhi College of Engineering
4	India gate	18	Hareoli
5	Lodhi Garden	19	Rohini Sector – 11
6	Safdarjung tomb	20	Singhola
7	Burarai	21	Asola
8	ISBT (Kashmiri Gate)	22	Hauz Khas
9	Majanu Ka Tila	23	Daulatpur
10	Ushmanpur	24	Dwarka Sec-16
11	Wazirabad	25	PUSA
12	Auchandi	26	Tagore Garden
13	Bakoli	27	Janakpuri
14	Balswa Lake	28	Peera Garhi

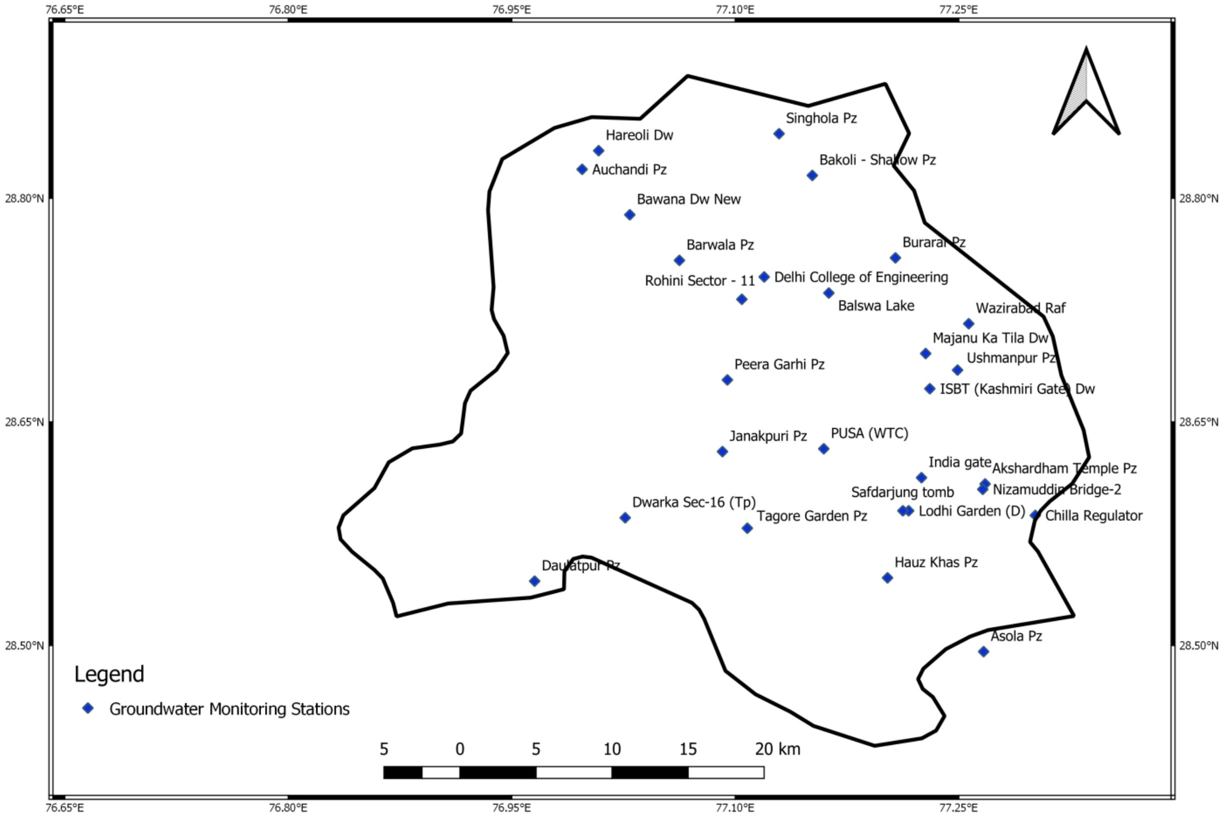

Fig 3.2: Map showing locations of sampling station in NCT Delhi

3.2.2 Drinking Water Quality Parameters

The data collected from the CGWB for the years 2010 and 2015 defined the quality of groundwater of NCT Delhi with respect to drinking purpose using 11 different parameters. The observed value has been compared with the standards given by Bureau of Indian Standards (BIS) 2012 to evaluate its quality with respect to human consumption.

Parameters used : pH, sulphate, potassium, chloride, total alkalinity, total hardness, nitrate, sodium content, magnesium content, calcium content and fluoride content.

The definition and importance of these water quality parameters are defined below.

i. **pH-** It measures how acidic or alkaline water is. In mathematically terms, pH is defined as the negative logarithm (base ten) of the concentration of hydrogen ion. pH of water varies from 0 to 14. If the pH is less than 7 then it is termed as acidic water, if pH is greater than 7 it is termed as alkaline water and if pH of water is 7 then it is termed as neutral. The acceptable range of pH of drinking water is 6.5-8.5.

ii. **Total Hardness-** Water during its flow through soil tends to dissolve minerals and metals and hardness is the result of such minerals. Hardness of water is defined as the presence of magnesium and calcium ions in the water. Carbonate and bicarbonate of magnesium and calcium causes temporary hardness while sulphates and chlorides of magnesium and calcium ions cause permanent hardness. Hardness is responsible for scaling in utensils and boilers , it causes incrustation and corrosion of pipes. It is expressed as milligrams of calcium carbonate equivalent per litre. Sawyer and McCarty (1967) classified the groundwater based on Total Hardness as given in Table 3.2.Acceptable limit of total hardness is 200 mg/l and cause for rejection is 600mg/l.

Table 3.2: Classification of water on the basis of Total Hardness (Sawyer and McCarty, 1967)

Total Hardness as $CaCO_3$ (mg/l)	Water Type
< 75	Soft
75-150	Moderately Hard
150-300	Hard
>300	Very Hard

iii. **Total Alkalinity**- It is defined as the quantity of ions present in water that will neutralize the hydrogen ions (H^+). Most common constituents of alkalinity are carbonate, bicarbonate and hydroxide ions. Alkalinity in water may be due to presence of minerals or due to mixing of atmospheric CO_2 in water or due to microbial decomposition of organic matter . It can cause incrustation of pipes and imparts bitter taste to water. It is expressed as mg/l as $CaCO_3$. Its acceptable limit is 200 mg/l and permissible limit is 600 mg/l.

iv. **Chloride content**- Mineral deposits, agricultural or irrigation discharges constituents the major sources of chloride in water. Chloride in groundwater is mostly in the form of sodium chloride. Its concentration in natural water varies widely and can be related to rock minerals such as chlorapatite and sodalite. Presence of chloride in high quantity imparts the salt taste and indicates pollution of water due to industrial or sewage water. If the chloride content increases, it increases the electrical conductivity of water and thus the water becomes more corrosive. It is expressed in milligrams per litre .Its acceptable range is 250 mg/l and permissible limit is 1000 mg/l.

v. **Nitrate content**- Nitrate, being highly soluble in water and having low retention by soil particles, is one of the major contaminant of groundwater in areas having nitrate formation. Presence of nitrate in water indicates presence of organic matter. It finds its way into the groundwater through non-point sources like from septic tanks and leaching of nitrogenous fertilizers. Nitrate in high concentration affects infants and causes blue baby disease or mathemoglobinemia. Its acceptable range is 45mg/l as per BIS 2012.

vi. **Fluoride content-** Fluoride is present in groundwater owing to natural or anthropogenic sources. Natural sources include weathering of fluoride bearing rock minerals like apatite while anthropogenic sources include leaching of fertilizers containing fluoride and combustion of coal . In arid and semi-arid regions, high temperature increases the evaporation rate and evaporation plays a significant role in distribution of fluoride (Farooqi et al. 2007). Fluoride upto1mg/l in drinking water is required to prevent dental cavities. Fluorides in correct amount make the teeth stronger and harder. If present in value greater than 1.5 mg/l results in decolouration of teeth called mottling of teeth and infants are affected by this. Greater than 5mg/l causes fluorosis. Acceptable limit is 1.0 mg/l and cause for rejection is 1.50 mg/l.

vii. **Sulphate content-** Sulphate is mostly found in all natural water as a result of industrial waste or because of the movement of the groundwater through sulphate minerals. Rain water also contains sulphate in dissolved form. Sulphates when present in water particularly having low alkalinity, causes corrosion of metals in the distribution system. The acceptable limit of sulphate according to BIS **IS: 10500-2012** is 200 mg/l and cause for rejection is 400 mg/l. Children are more sensitive to sulphate than the adults as it can cause dehydration and diarrhea. It proves to be corrosive for plumbing especially in case of copper piping.

viii. **Calcium content**- Calcium occurs naturally in water as it may dissolve from rocks such as gypsum, limestone, marble etc. Calcium solutions such as $CaCl_2$ or $Ca(NO_3)$ are applied to horticulture as fertilizers. The sulphates and carbonates of Calcium are soluble in water. The acceptable limit of calcium in water is 75 mg/l and the permissible limit is 200 mg/l. Calcium is essential for bones and teeth formation. It is largely responsible for water hardness.

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca(HCO_3)_2 \quad \textbf{(3.1)}$$

Calcium carbonate being soluble in water, continuously dissolves as long as water is acidic. Precipitation of calcium carbonate occurs when pH is beyond 8.2 or due to increase in temperature or evaporation.

ix. **Magnesium content** – Magnesium is a constituent of large number of rocks and from there it gets washed away and subsequently ends up in water. Magnesium also contributes to water hardness and negatively influences the cleansing properties of soaps and detergents. Magnesium carbonate gets converted into magnesium bicarbonate which is soluble in water in presence of carbonic acid.

$$MgCO_3+CO_2+H_2O \leftrightarrow Mg(HCO_3)_2 \quad \textbf{(3.2)}$$

The solubility of magnesium carbonate under ordinary conditions is almost ten times than that of calcium carbonate in water in the presence of carbon dioxide . In groundwater, the calcium content generally exceeds the magnesium content due to relative abundance of calcium in rocks. Low levels of magnesium in drinkimg water are known to cause hypertension and osteoporosis while high levels are known to cause diarrhea and laxative effect in humans . The acceptable limit of magnesium in drinking water is 30 mg/l and permissible limit is 100 mg/l.

x. **Sodium content**- Sodium is highly soluble in natural water and it occurs as a result of weathering process. Sewage effluents, mineral deposits and saline intrusion contribute significant amount of sodium in natural water. Groundwater having considerate amount of sodium carbonate or sodium bicarbonate is said to be alkaline in nature. BIS has not prescribed any standard limit of sodium in drinking water.

xi. **Potassium content**- Potassium is almost as abundant as sodium in rocks but when it comes to concentration in groundwater it is about one-tenth or in some cases one-hundredth of sodium. Potassium salts are more soluble as compared to sodium salts. Potassium is generally found in water as a result of leaching and runoff on organic residues. In a study conducted by Datta et al. (1997), it was found that in many areas of Delhi, the concentration of potassium in groundwater exceeds the acceptability limit. The reason behind this could be the non-point sources from frequent use of fertilizers, unlimited discharge of waste directly in drains and on land. BIS has not prescribed any standard limit of potassium in drinking water.

3.2.3 Drinking Water Quality Standards

The water quality standard suggested by Bureau of Indian Standards (BIS) for drinking use was used in the development of the water quality index and in analyzing the suitability of groundwater for drinking purposes.

The Drinking water standard suggested by the BIS is given in Table 3.3.

Table 3.3: Indian Standards Drinking Specifications (2012)

S.No	Parameters	Desirable Limit	Permissible Limit in absence of alternate source
1	pH	6.5-8.5	No relaxation
2	Total Hardness(as $CaCO_3$)	200 mg/l	600 mg/l
3	Total Alkalinity (as $CaCO_3$)	200 mg/l	600 mg/l
4	Calcium	75 mg/l	200 mg/l
5	Magnesium	30 mg/l	100 mg/l
6	Chloride	250 mg/l	1000 mg/l
7	Nitrate	45 mg/l	No relaxation
8	Fluoride	1.0 mg/l	1.5 mg/l
9	Sulphate	200 mg/l	400 mg/l
10	Sodium	-	-
11	Potassium	-	-

3.2.4 Irrigation Water Quality

Groundwater is largely used for irrigation purpose. The quality of irrigation water depends on the chemical composition of the groundwater. Various minerals present in the groundwater effects the plants and soil and decide whether the groundwater is suitable for irrigation or not.

The criteria used for assessing the quality of groundwater to be used as irrigation water are Salinity Hazard, Sodium Adsorption Ratio (SAR), Permeability Index(PI) and Sodium Percentage(Na%).

i. **Salinity Hazard**– Irrigation water with high salt content poses a salinity hazard. Soils with high content of salinity are termed as Saline soils. The salinity of water is expressed either in terms of Electrical conductivity (μS/cm) or in terms of Total Dissolved Solids (mg/l). When irrigation water containing higher percentage of salt content evaporates, they leave behind the minerals and salts. These salts accumulate in the soil and affect the growth of plants by reducing their ability to extract water from the soil. So higher the salt content in the irrigation water higher is the osmotic pressure in the soil (Thorne and Peterson 1954).

ii. **Sodium Adsorption Ratio (SAR)** – SAR is a better measure of Sodium Hazard and is used to express reactions with soil. SAR and EC can be reciprocally be used to assess the quality of irrigation water. Higher is the SAR, lower is the suitability of groundwater to be used as irrigation water. SAR is calculated using the formula given by Wilcox (1955):

$$\mathbf{SAR} = \frac{\mathbf{Na^{+}}}{\sqrt[2]{\frac{\mathbf{Ca^{+2}+Mg^{+2}}}{\mathbf{2}}}} \qquad \textbf{(3.3)}$$

Where Ca, Mg and Na are expressed in meq/l (milliequivalents of solute per litre of solvent) .

iii. **Permeability Index (PI) –** Permeability Index (PI) explains the combined effect of sodium, calcium, magnesium and bicarbonate ions on soil permeability. In long term it affects the soil permeability. The permeability index of the groundwater was calculated as explained by Doneen (1964) and Ragunath (1987) and is represented in equation 3.4.

$$\mathbf{PI} = \frac{\mathbf{Na^{+}} + \sqrt{\mathbf{HCO_3^{-}}}}{(\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}} + \mathbf{Na^{+}})} * \mathbf{100} \qquad \textbf{(3.4)}$$

where all concentrations are in meq/l.

iv. **Percent Sodium (Na %)** – Percent Sodium is also an important parameter for deciding the suitability of irrigation water. When the concentration of Sodium percent is high in irrigation water, it tends to displace the magnesium and calcium ions present in the soil. This replacement in soil results in low permeability and internal drainage of soil also gets affected. Eventually the soil becomes hard and dry (Saleh et al.1999).

Na % can be computed by the following equation:

$$\mathbf{Na}\ \% = \frac{\mathbf{Na^{+}} + \mathbf{K^{+}}}{\mathbf{Ca^{2+}} + \mathbf{Mg^{2+}} + \mathbf{Na^{+}} + \mathbf{K^{+}}} * \mathbf{100} \qquad \textbf{(3.5)}$$

Where concentration are in meq/l.

3.3 Water Quality Index

Water quality index provide unique rating to describe the overall quality of water in a single value that helps in the selection of appropriate treatment method (Tyagi et al.2013). These indices work as a tool that converts large data into a single entity which can be easily assessed. Development of WQI involves three main steps (US EPA 2009):

i. Obtain the data regarding individual water quality indicators.
ii. Transform these data into sub-index values so that they can be represented on a common scale.
iii. Aggregate the individual sub index values of water quality parameters to get an overall WQI value.

Hortan (1965) developed the arithmetic aggregation function for the WQI using 10 commonly measured water quality parameters including pH, Dissolved oxygen (DO), Specific conductance (EC), chloride and alkalinity. Weights ranged from 1 to 4. Similarly Brown et.al (1970) also employed basic arithmetic weightage for the development of WQI without using the multiplicative variables.

In this study, the weighted arithmetic mean method for development of Water Quality Index for drinking purpose is used. It involved 4 steps (Shah and Joshi , 2017):

i. Selection of water quality parameters for the development of WQI.
ii. Assigning unit weights (w_i) to each parameters ranging from 1 to 5 and then calculating the relative weight of each selected parameter (W_i).
iii. Estimation of Quality rating scale (Q_i) for each selected parameter.

iv. Determining the sub-index value (W_i x Q_i) and aggregating them to obtain the overall WQI.

These steps are explained in detail in following sub-headings.

3.3.1 Selection of Parameters

The different water quality parameters selected for the calculation of WQI for the drinking purpose is listed in table 3.4.

Table 3.4: Parameters selected for the estimation of WQI for drinking purpose.

S.No	Parameters
1	pH
2	Total Alkalinity
3	Total Hardness
4	Sulphate
5	Chloride
6	Nitrate
7	Fluoride
8	Calcium
9	Magnesium
10	Sodium
11	Potassium

3.3.2 Assigning weightage to Parameters

Unit weights (w_i) ranging from 1 to 5 are assigned to selected parameters based on their importance in evaluation of drinking water quality: five representing the maximum weight. Then “relative weight factor” can be determined by dividing the individual parameter unit weights by the sum of all the unit weights (Gupta et al., 2003; Debels et al., 2005;Boyaciolu, 2007) as described in equation 3.6.

$$\boldsymbol{Wi = \frac{wi}{\sum_{i=1}^{n} wi}} \qquad \textbf{(3.6)}$$

Where, W_i = relative weight of each parameter.

w_i = unit weight assigned to each parameter.

n = total number of parameters i.e n= 11

In this manner relative weight for each selected parameter is calculated and is shown in table 3.5.

Table 3.5: Relative weights of Drinking water quality Parameters

Parameters	Indian Standard (Si)	Weights (wi)	Relative weight (Wi)
pH	6.5-8.5	4	0.121
Total Alkalinity	200-600	3	0.091
Total Hardness	200-600	3	0.091
Sulphate	200-400	4	0.121
Chloride	250-1000	4	0.121
Nitrate	45	5	0.152
Fluoride	1.0-1.5	4	0.121
Calcium	75-200	2	0.061
Magnesium	30-100	2	0.061
Sodium*	200	1	0.030
Potassium*	10	1	0.030
Σ		**33**	1.00

*****(In case of sodium and potassium, BIS has not prescribed any standard limit. Here for evaluation of WQI, a limit of 200 mg/l and 10 mg/l are taken for Sodium and Potassium respectively)

3.3.3 Estimation of Quality rating Scale (Q_i)

The next step is to calculate the quality eating scale (Q_i) for each selected parameter. The quality rating is calculated using the equation given by Brown et al. (1970).

$$\mathbf{Q_i = \frac{(V_a - V_i)}{(S_i - V_i)} \times 100} \quad \textbf{(3.7)}$$

Where**,**

V_a and V_i = The actual and ideal values for all the selected parameters of water quality respectively. The value of V_i is zero for all the parameters except for pH. For pH value of V_i is 7.

S_i = Standard value of selected parameter taken from BIS **2012.**

3.3.4 Aggregation of Water Quality Index (WQI)

The next and the final step is to calculate the sub indices value of each selected parameter and aggregating them together to obtain the overall Water Quality Index (WQI). It is done by aggregating the quality rating with the relative weights linearly as described by Brown et al. (1970) .

$$\mathbf{WQI = \sum_{i=1}^{n} W_i \ x \ Q_i} \quad \textbf{(3.8)}$$

Where, W_i and Q_i are the relative weight and quality rating for the i^{th} parameter.

3.4 GIS MODEL FOR MAPPING

Geographic Information System (GIS) proved to be a robust tool for solving the water related problems which include assessment of water quality using different water quality indicators, estimation of water availability, prevention of floods, developing better understanding of natural environment and management of water resources on a regional scale (Collet,1996). GIS allows interpolating the water quality parameters at unknown locations using the data of known locations to create continuous surface. This feature will help us to develop a better understanding of water quality of the study area. Inverse Distance Weighted (IDW) is a raster interpolation technique available in QGIS software (version 3.10.2) and this spatial interpolation technique is used in the present study to delineate the local distribution of water quality parameters and water quality index (WQI).

The map of NCT Delhi is geo-referenced using the geo-referencing tool available in the QGIS software. The shape file of the NCT Delhi was created using the layer tools of QGIS software and converting the created shape file raster into vector. The locations of different sampling stations were imported into the software through point layer in the form of comma separated file (.csv). Each sample station was provided a unique code and was stored in a point attribute table. The database file contained separated columns for values of all chemical parameters including unique code for each sampling site. Inverse Distance weighted (IDW) interpolation technique was used along with contour tool of the software for better representation of spatial distribution of water quality parameters on the thematic maps. The scale used to prepare the maps is 1:250000.

CHAPTER 4

RESULTS AND DISCUSSIONS

The present study aims to analyze and compare the groundwater quality of National Capital Territory (NCT) Delhi using the CGWB data for the year 2010 and 2015 so as to assess its suitability for human consumption and irrigation use. The results of the study have been presented below in sub-headings.

4.1 DRINKING WATER QUALITY

Groundwater chemical composition depends on the geochemical process which occurs when the water reacts with the geologic material through which it flows (Appelo and Postma, 1996). In this study eleven parameters have been considered for the assessment of water quality of groundwater for human consumption. These parameters are pH, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, fluoride, chloride , sulphate and nitrate. The data of the groundwater quality for drinking purpose is presented in the table A2.1 and A2.2 for the years 2010 and 2015 respectively and they are discussed in detailed as follows:

4.1.1 pH

pH measures how acidic or alkaline the water is. The permissible range of pH as suggested by BIS (2012) is 6.5-8.5. If the pH value is less than 4, it indicates that the water is acidic and it is corrosive in nature. pH value greater than 7 indicates that the water is alkaline in nature and impart bitter taste to water.

In 2010, the pH of the groundwater in the study area varied from 6.8 in Hauz Khas to 8.95 in Dwarka Sector-16 . Except at 2 stations i.e Rohini Sector-11 and Dwarka Sector-16 , the pH of all other stations were lying within the permissible range and were suitable for human consumption.

In 2015, the pH varied from 7.55 in Barwala to 8.77 in Delhi College of Engineering. It shows that most of the areas had pH values lying in the permissible range and were suitable for human consumption as per BIS.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the pH of 18 monitored stations i.e Nizamuddin Bridge-2, Hauz Khas, Safdarjung tomb, Ushmanpur. Akshardham Temple, Delhi College of Engineering, Asola, Bakoli, Wazirabad , Chilla Regulator, Majanu Ka Tila, ISBT(Kashmere Gate), Janakpuri , Rohini Sector-11, Daulatpur, Auchandi, Lodhi Garden and Hareoli had increased while 10 monitored stations i.e India Gate, Bawana, PUSA, Dwarka Sector-16, Burarai , Tagore Garden, Balswa Lake, Peera Garhi, Barwala and Singhola Pz had recorded lesser pH values. So overall the pH of the study area had been increased over the gap of five years from 2010 to 2015 .

The spatial distribution of pH in the groundwater across the city is shown in fig 4.1 and fig 4.2 for the years 2010 and 2015 respectively.

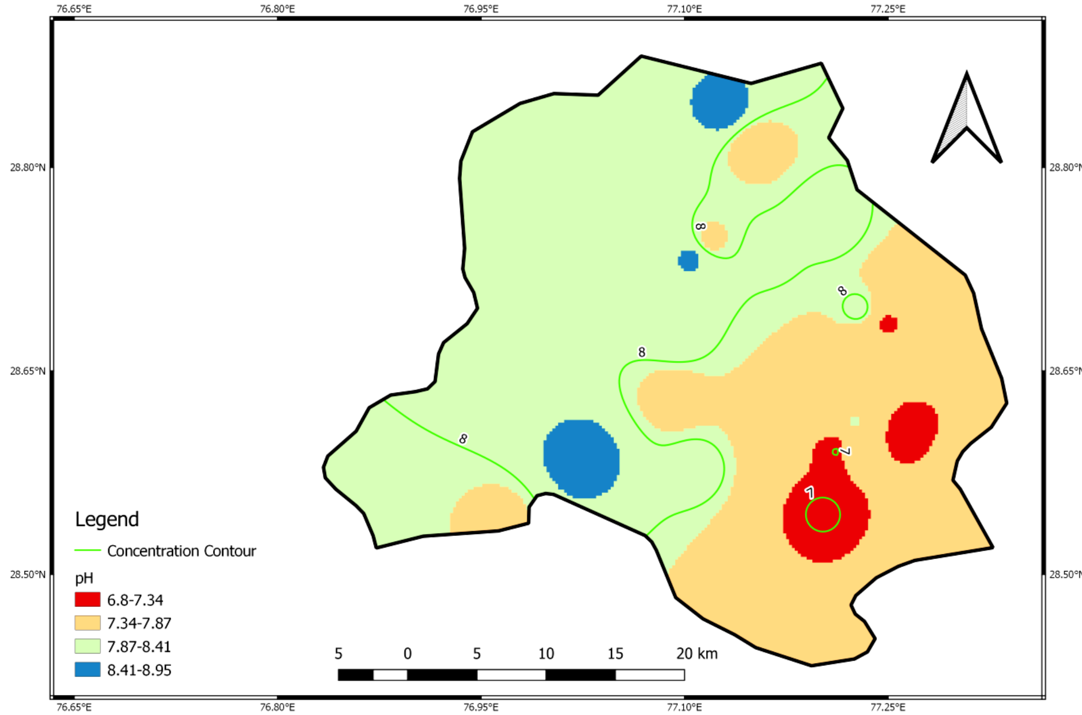

Fig 4.1: Spatial Distribution of pH in groundwater in NCT Delhi in 2010

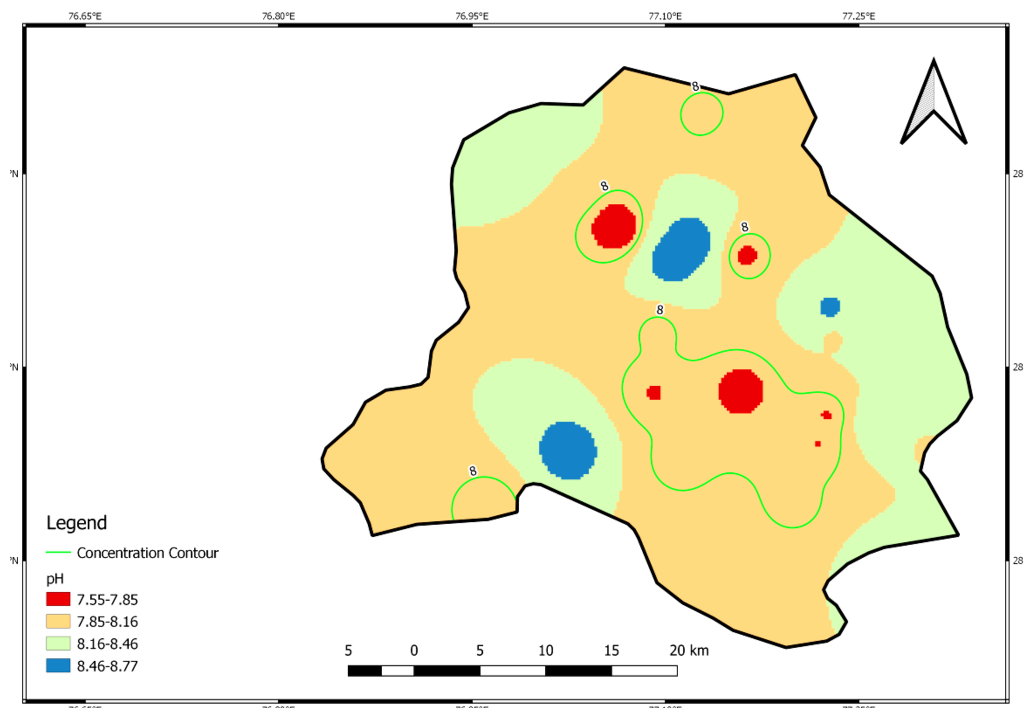

Fig 4.2: Spatial Distribution of pH in groundwater in NCT Delhi in 2015

4.1.2 Total Hardness

The permissible limit of total hardness for drinking water is 600 mg/l (as $CaCO_3$) as suggested by BIS (2012). In 2010, the total hardness in the groundwater of the study area varied from 159 mg/l (as $CaCO_3$) in Majanu ka Tila to 3358 mg/l (as $CaCO_3$) in Janakpuri. The spatial distribution of total hardness in the groundwater in the study area for the year 2010 is shown in fig 4.3. It can be concluded that North west part of the study area had high content of total hardness in groundwater.

In 2015, the total hardness varied from a minimum value of 185 mg/l (as $CaCO_3$) in Nizamuddin Bridge-2 to 2536 mg/l(as $CaCO_3$) in Barwala. The spatial distribution of total hardness in the groundwater in the study area for the year 2015 is shown in fig 4.4. It can be concluded that North west part of the study area had high content of total hardness in groundwater.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the total hardness of 11 monitored stations i.e ISBT(Kashmere Gate), Akshardham Temple , Majanu Ka Tila, Rohini Sector-11, Bakoli, Delhi College of Engineering, Barwala , Wazirabad , India Gate, Chilla Regulator and Lodhi Garden had increased while 17 monitored stations i.e, Singhola , PUSA, Asola, Ushmanpur , Dwarka Sector-16, Balswa Lake, Hareoli , Safdarjung tomb, Daulatpur, Auchandi, Tagore Garden, Janakpuri , Burarai , Hauz Khas, Bawana ,Nizamuddin Bridge-2 and Peera Garhi, and had recorded lesser total hardness values. So overall the total hardness of the study area had been decreased over the gap of five years from 2010 to 2015 . The higher concentration of hardness was maybe due to surface ruoff or natural accumulation of salt or direct entry of waste water by human activities.

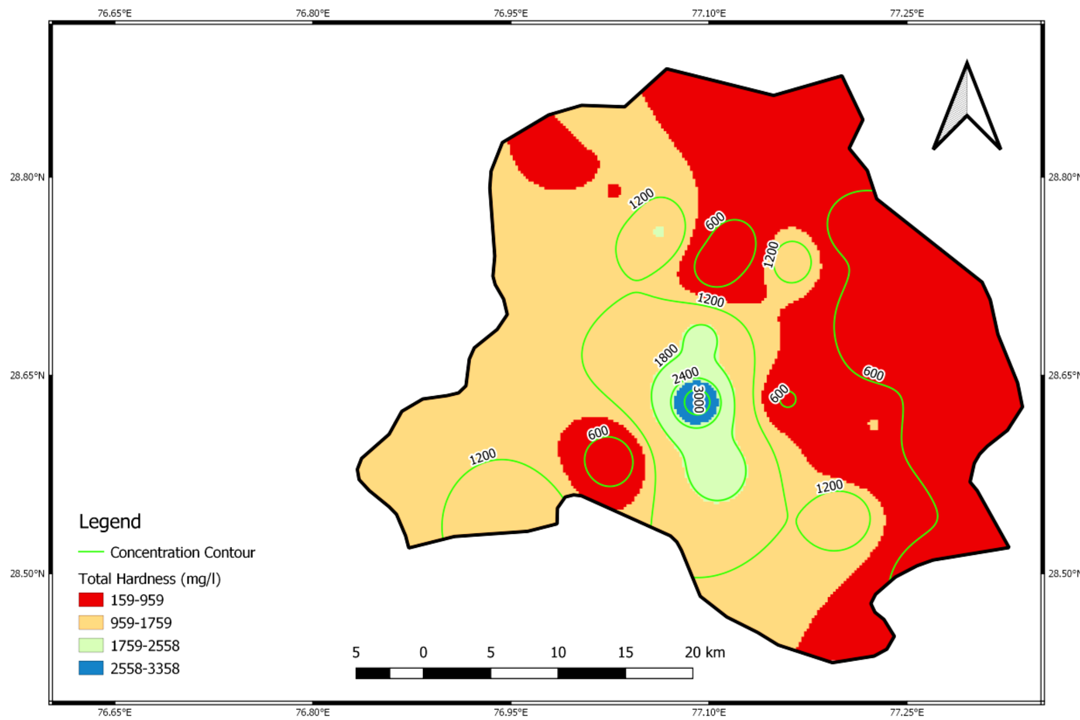

Fig 4.3: Spatial Distribution of Total hardness in groundwater in NCT Delhi in 2010

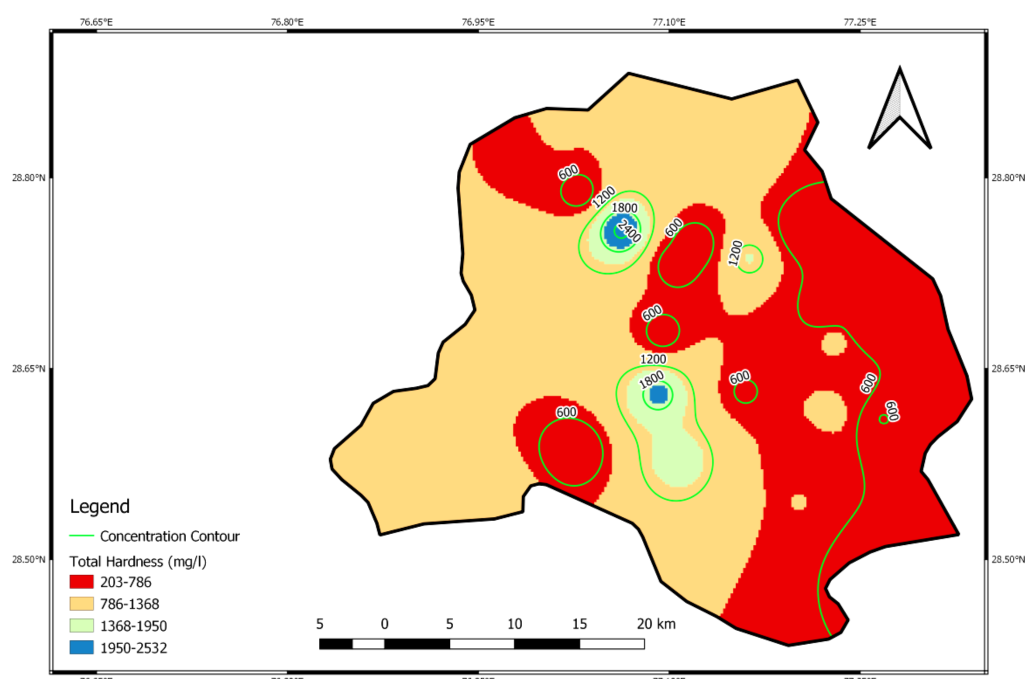

Fig 4.4: Spatial Distribution of Total hardness in groundwater in NCT Delhi in 2015

4.1.3 Total Alkalinity

The acceptable and maximum permissible value of total alkalinity in drinking water as suggested by BIS (2012) is 200 mg/l and 600 mg/l respectively. In year 2010, the Total Alkalinity in the groundwater of the study area varied from zero in areas like Majanu ka Tila and Safdarjung tomb to 557.38 in Balswa Lake. The spatial distribution of total alkalinity in the study area for the year 2010 is shown in fig 4.5. It can concluded that all the groundwater monitoring stations were having total alkalinity within the permissible range.

In 2015, the total alkalinity in the groundwater varied from a minimum value of 2.3mg/l in Chilla Regulator to a maximum value of 441.45 in Dwarka Sector-16. The spatial distribution of Total Alkalinity in the groundwater of NCT Delhi for the year 2015 is represented in fig 4.6. It shows that the groundwater in the study area was having alkalinity within permissible range.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the total alkalinity of 07 monitored stations i.e Safdarjung tomb, PUSA, Daulatpur ,Wazirabad , ISBT (Kashmere Gate), Delhi college of Engineering and Majanu ka Tila had increased while 21 monitored stations i.e, Asola, Janakpuri, Rohini Sector-11, Ushmanpur, Dwarka Sector-16, Lodhi Garden, Tagore garden, Barwala, Hareoli, Hauz Khas , Bawana, ,Nizamuddin Bridge-2 Bakoli, Auchandi, India Gate, Peera Garh, Akshardham Temple, Balswa lake, Burarai, Singhola and Chilla Regulator had recorded lesser total alkalinity values. So overall the total alkalinity of the study area had been decreased over the gap of five years from 2010 to 2015.

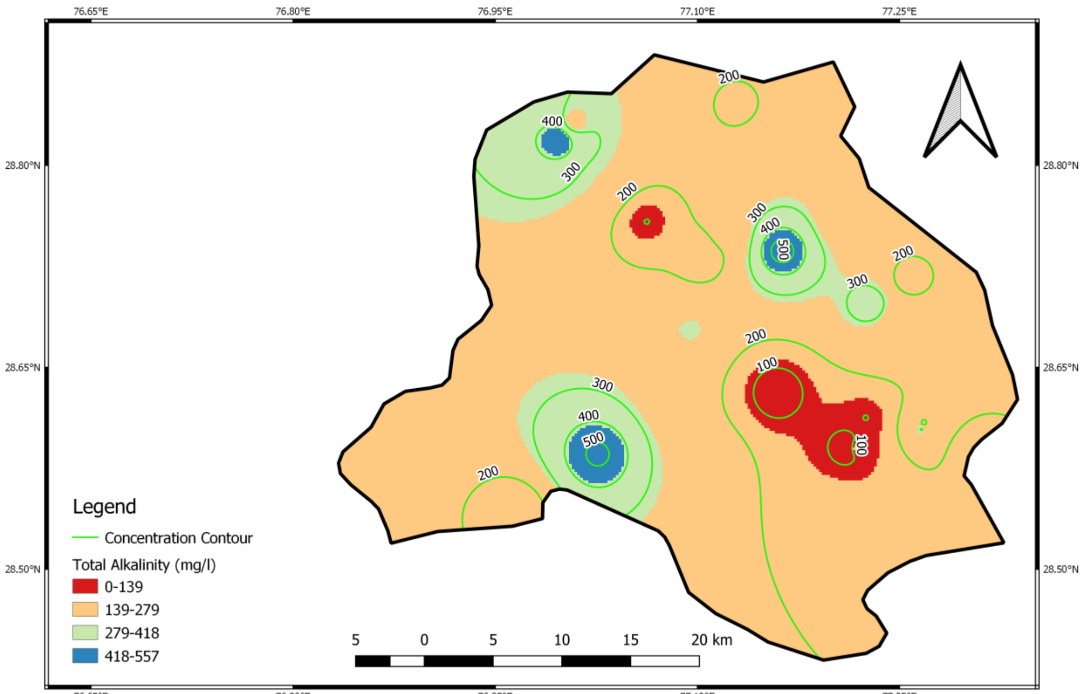

Fig 4.5: Spatial Distribution of Total Alkalinity in groundwater in NCT Delhi in 2010

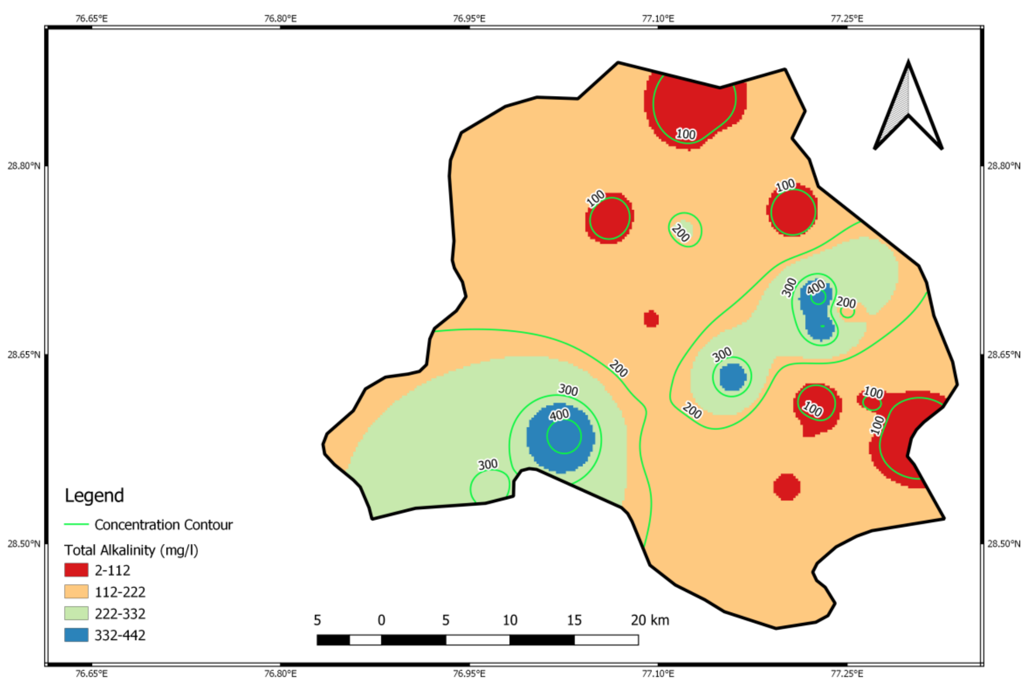

Fig 4.6: Spatial Distribution of Total Alkalinity in groundwater in NCT Delhi in 2015

4.1.4 Calcium

The desirable and the maximum permissible limit of Calcium in drinking water as per BIS (2012) is 75 mg/l and 200 mg/l respectively. In 2010, the calcium content in the groundwater of the study area varied from 6.4 mg/l in Asola to 655 mg/l in Janakpuri. The spatial distribution of the calcium in the groundwater of the study area is shown in fig 4.7. It can be concluded that West Delhi and parts of South West Delhi had higher content of calcium in groundwater.

In year 2015, the distribution of calcium in study area varied from 8 mg/l in Dwarka Sector-16 to 513 mg/l in Janakpuri. The spatial distribution of calcium in the groundwater in NCT Delhi is shown in fig 4.8. It shows that except at four locations namely: Janakpuri, Tagore Garden , Balswa Lake and Barwala , calcium content in all the sampling found within the permissible range.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the calcium content of 06 monitored stations i.e, Asola, Singhola, ISBT (Kashmere Gate), Bakoli, Akshardham Temple and Wazirabad , had increased while 22 monitored stations i.e, dElhi College of Engineering, Tagore garden , Barwala, India Gate, Janakpuri, Lodhi Garden, Balswa lake, Daulatpur, Safdarjung tomb, Hareoli, PUSA, Auchandi , Chilla Regulator , Hauz Khas , Majanu ka Tila , Bawana , Rohini Sector-11, Dwarka Sector-16, Ushmanpur, Burarai , Peera Garhi and Nizamuddin Bridge-2 had recorded lesser calcium content. So overall the calcium content of the study area had been decreased over the gap of five years from 2010 to 2015.

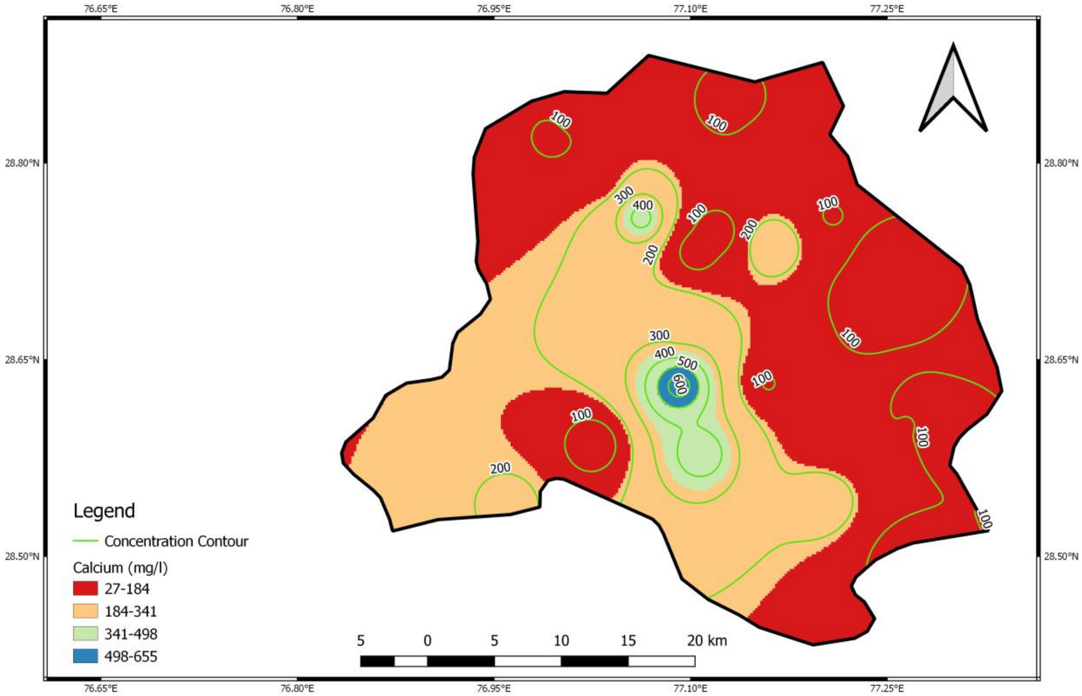

Fig 4.7: Spatial Distribution of Calcium in groundwater in NCT Delhi in 2010

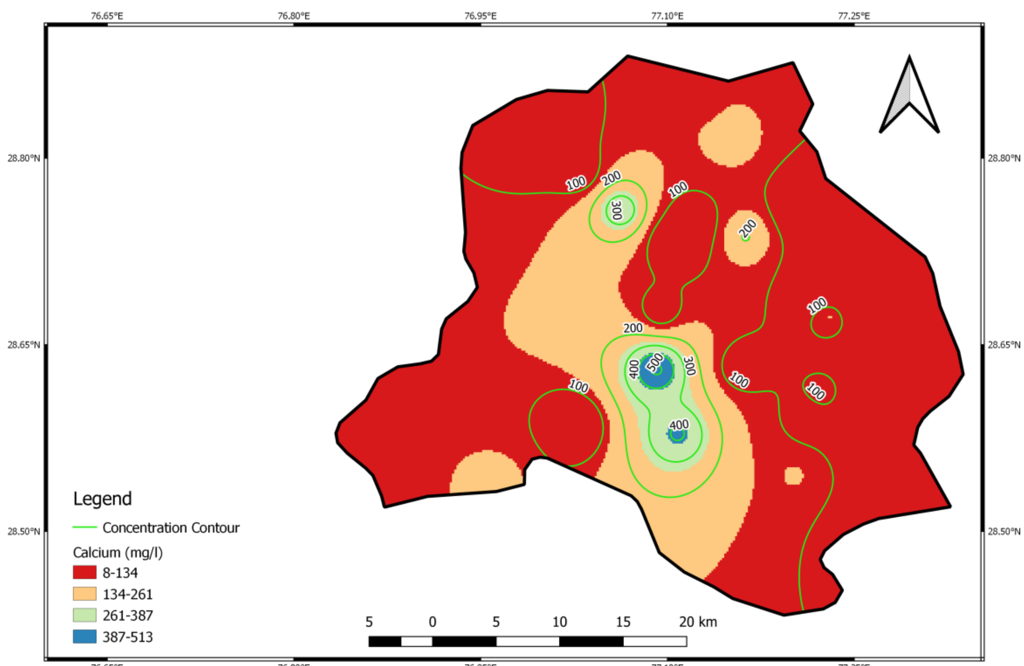

Fig 4.8: Spatial Distribution of Calcium in groundwater in NCT Delhi in 2015

4.1.5 Magnesium

The desirable and the maximum permissible limit of magnesium in drinking water as suggested by BIS (2012) is 30mg/l and 100 mg/l respectively. In year 2010, the magnesium content in the groundwater of the study area varied from 7.8 mg/l in Majanu ka Tila to 418 mg/l in Janakpuri. The spatial distribution of magnesium in groundwater of the study area is shown in fig 4.9. It shows that North West Delhi, West Delhi, parts of South West Delhi had higher content of magnesium in groundwater.

In year 2015,the distribution of magnesium in the study area was varied from 31mg/l in Nizamuddin Bridge-2 to 387 mg/l in Barwala . The spatial distribution of magnesium in groundwater in NCT Delhi is shown in Fig 4.10. It shows that high concentration of magnesium was found at East and North West part of the city.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the magnesium content of 17 monitored stations i.e Majanu ka Tila , ISBT (Kashmere Gate), Akshardham Temple , Rohini Sector-11, Delhi College of Engineering, Barwala, Chilla Regulator , Ushmanpur , PUSA, Bakoli, Lodhi Garden, Burarai , Nizamuddin Bridge-2 , India Gate, Wazirabad , Dwarka Sector-16 and Balswa lake had increased while 11 monitored stations i.e, Safdarjung tomb, Hareoli, Auchandi , Daulatpur, Singhola, Asola, Tagore garden , Bawana , Janakpuri, , Hauz Khas and Peera Garhi had recorded lesser magnesium content. So overall the magnesium content of the study area had been increased over the gap of five years from 2010 to 2015.

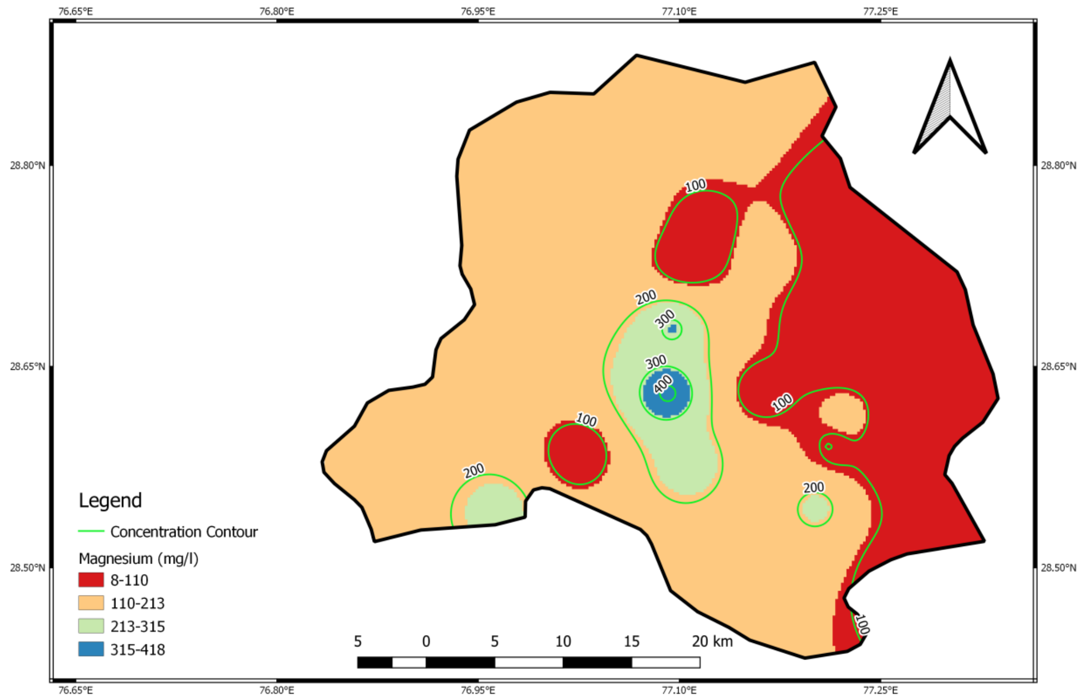

Fig 4.9: Spatial Distribution of Magnesium in groundwater in NCT Delhi in 2010

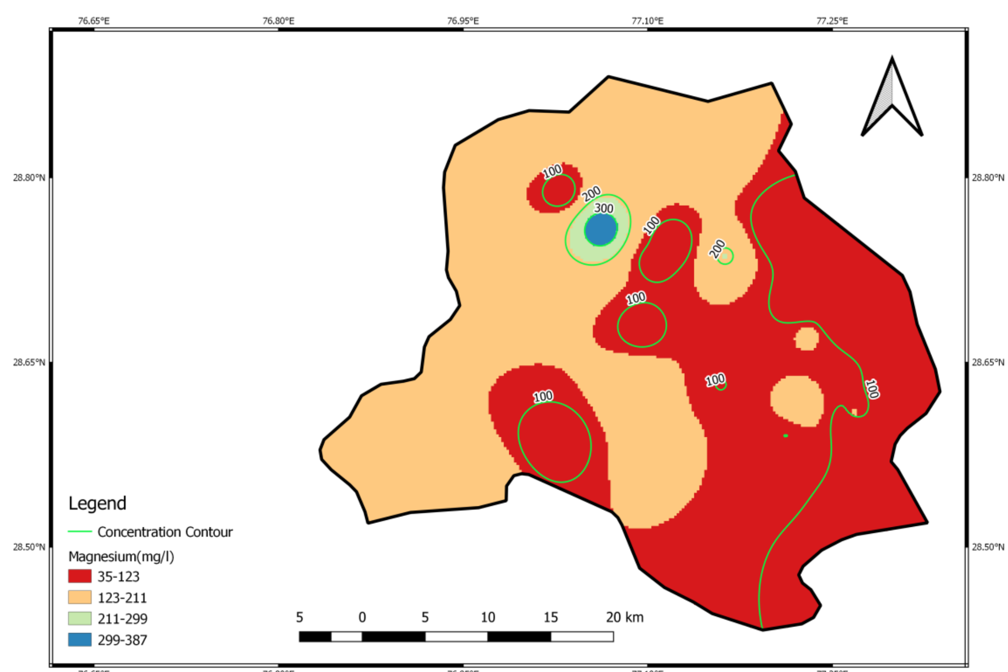

Fig 4.10: Spatial Distribution of Magnesium in groundwater in NCT Delhi in 2015

4.1.6 Sodium

BIS has not prescribed any standard limit of sodium in drinking water. Higher intake of sodium proves harmful to persons suffering from hypertension or heart disease. At room temperature, the average taste threshold for sodium is about 200 mg/l (Singh and Hussain, 2016). In year 2010, the sodium content in the groundwater of the study area varied from 25 mg/l in Rohini Sector-11 to 1725 mg/l in Tagore Garden. The spatial distribution of sodium in groundwater of the study area is shown in fig 4.11. It shows that West Delhi had higher content of magnesium in groundwater.

In year 2015, the distribution of sodium in groundwater in the study area was varied from 31mg/l in Chilla Regulator to 2477 mg/l in Tagore Garden. The spatial distribution of sodium in groundwater in NCT Delhi is shown in Fig 4.12. It shows that all the monitoring stations located in North West Delhi had high content of sodium in groundwater.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the sodium content of 19 monitored stations i.e Barwala, Rohini Sector-11, Bakoli, Daulatpur, Delhi College of Engineering, Safdarjung tomb, Lodhi Garden, Asola, Singhola, India Gate, Akshardham Temple , PUSA, Tagore garden , ISBT (Kashmere Gate), Janakpuri, Majanu ka Tila , Nizamuddin Bridge-2 , Ushmanpur and Balswa lake had increased and while 09 monitored stations i.e, Hareoli, Dwarka Sector-16 , Chilla Regulator, Hauz Khas , Wazirabad , Bawana , Burarai , Auchandi and Peera Garhi had recorded lesser sodium content. So overall the sodium content of the study area had been increased over the gap of five years from 2010 to 2015.

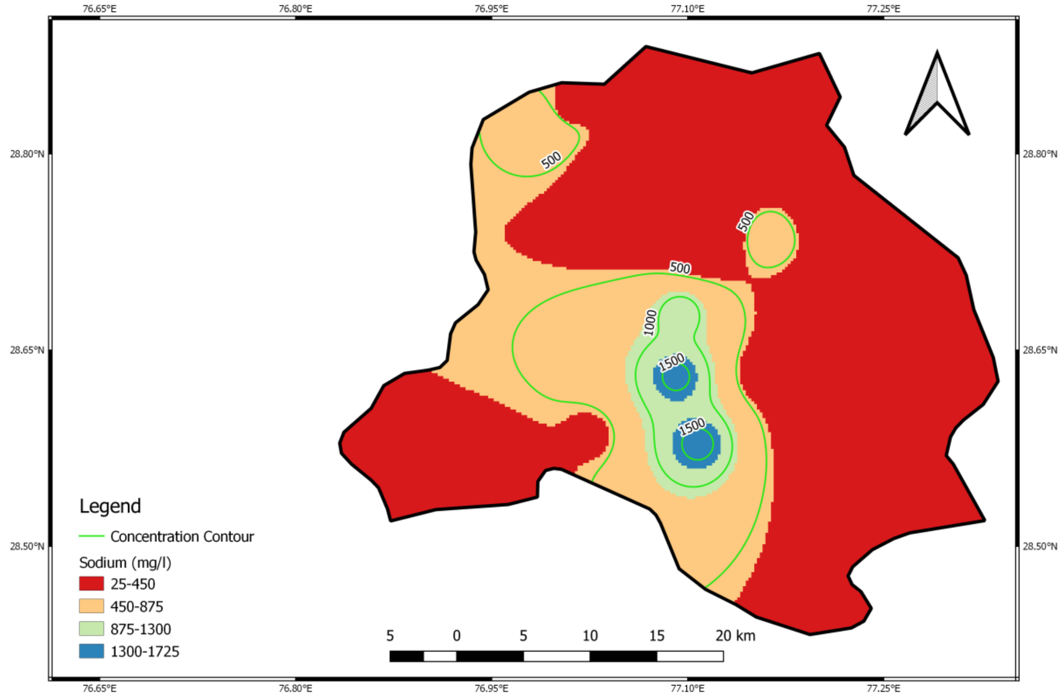

Fig 4.11: Spatial Distribution of Sodium in groundwater in NCT Delhi in 2010

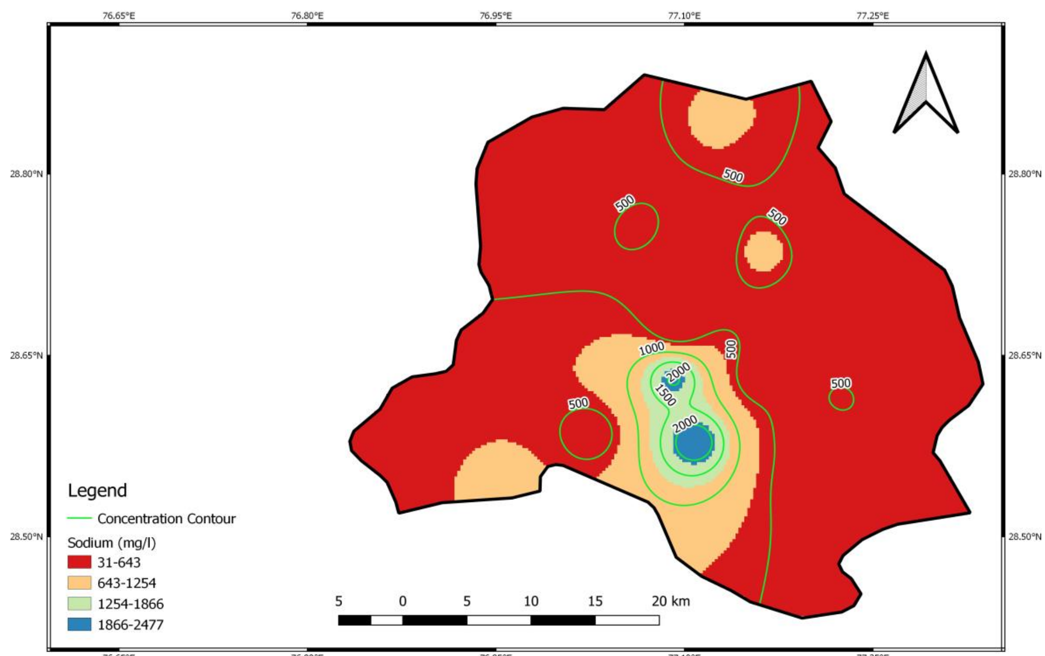

Fig 4.12: Spatial Distribution of Sodium in groundwater in NCT Delhi in 2015

4.1.7 Potassium:

BIS (2012) has not suggested any limit of potassium in drinking water as it is not harmful in smaller concentrations. A maximum concentration of 10 mg/l of potassium in drinking water is taken here as a upper limit (Singh et al. 2011). In year 2010, the potassium content in the groundwater of the study area varied from 01 mg/l in Hauz Khas to 69 mg/l in Majanu ka Tila. The spatial distribution of potassium in groundwater of the study area is shown in fig 4.13. It shows that West Delhi had higher content of potassium in groundwater.

The distribution of potassium in groundwater of the study area was varying from 1 mg/l in PUSA to 110 mg/l in Majanu ka Tila . The spatial distribution of potassium in groundwater in NCT Delhi is shown in fig 4.14.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the potassium content of 17 monitored stations i.e Ushmanpur , Rohini Sector-11, Hareoli, Barwala, Bawana , Dwarka Sector-16, Daulatpur, Burarai , India Gate, Hauz Khas, Asola, Wazirabad , Balswa lake, Safdarjung tomb, Majanu ka Tila , Bakoli and Chilla Regulator had increased and while 08 monitored stations i.e, Auchandi , Tagore garden , Peera Garhi , Delhi College of Engineering, ISBT (Kashmere Gate), Janakpuri , PUSA and Akshardham Temple had recorded lesser potassium content. Three stations namely Singhola, Nizamuddin Bridge-2 and Lodhi Garden had same content of potassium in both years. So overall the potassium content of the study area had been increased over the gap of five years from 2010 to 2015.

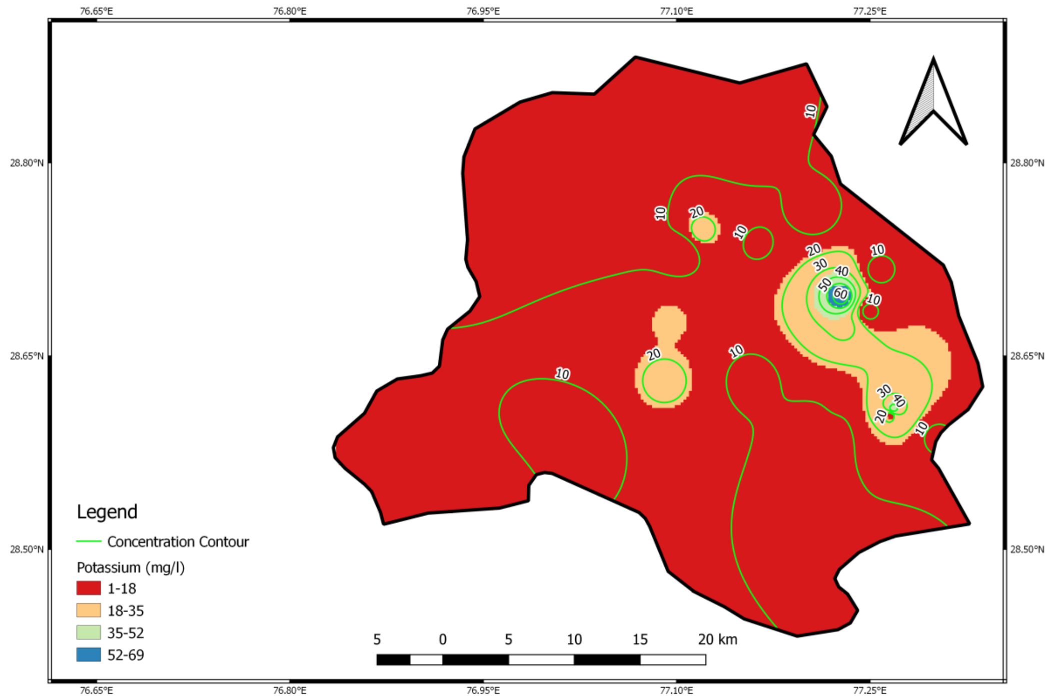

Fig 4.13: Spatial Distribution of Potassium in groundwater in NCT Delhi in 2010

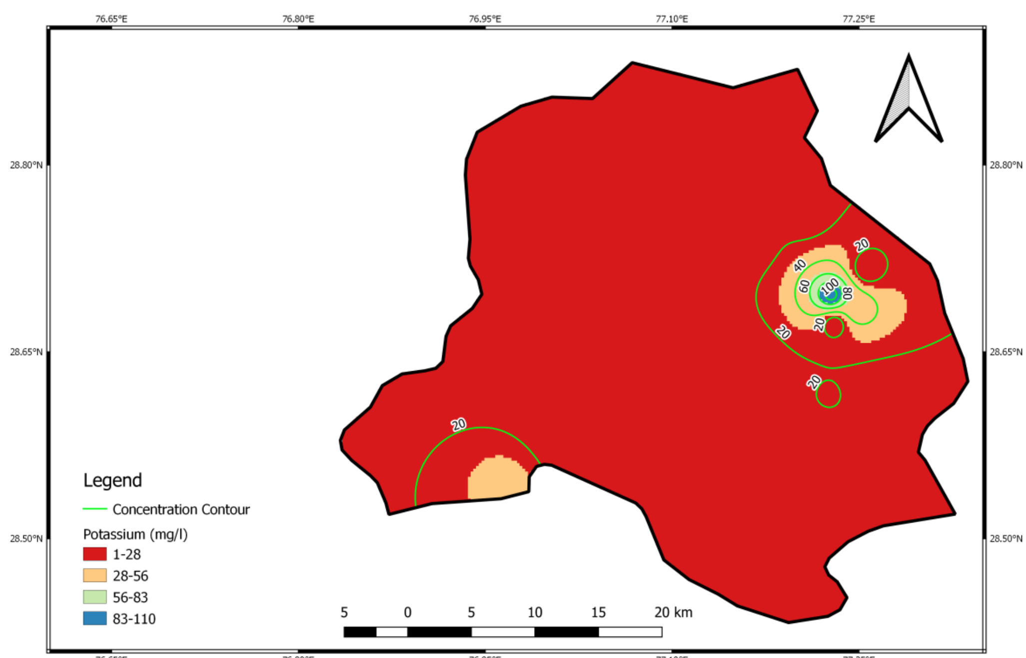

Fig 4.14: Spatial Distribution of Potassium in groundwater in NCT Delhi in 2015

4.1.8 Chloride

The desirable and the maximum permissible limit of chloride in drinking water as per BIS (2012) is 250 mg/l and 1000 mg/l respectively. In year 2010, the chloride content in the groundwater of the study area varied from 18 mg/l in Delhi College of Engineering to 4176 mg/l in Janakpuri. The spatial distribution of chloride in groundwater of the study area is shown in fig 4.15. It shows that West Delhi and parts of North West Delhi had higher content of chloride in groundwater.

The concentration of chloride in groundwater in the study area during year 2015 varied from 85 mg/l in Burari to 2204 mg/l in Tagore Garden. The spatial distribution of chloride in groundwater in NCT Delhi is shown in Fig 4.16. It shows that parts North West Delhi and parts of South West Delhi of the study area had high concentrations of chloride in groundwater.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the chloride content of 17 monitored stations i.e Rohini Sector-11, Delhi College of Engineering, Akshardham Temple , Chilla Regulator , Barwala, Safdarjung tomb, Bakoli, Asola, Singhola, ISBT (Kashmere Gate), PUSA, Tagore garden , Lodhi Garden, Dwarka Sector-16, Daulatpur, India Gate, and Majanu ka Tila had increased and while 11 monitored stations i.e Ushmanpur , Balswa lake, Nizamuddin Bridge-2 , Auchandi , Hareoli, Hauz Khas, Janakpuri, Wazirabad , Burarai , Bawana and Peera Garhi had recorded lesser chloride content. So overall the chloride content of the study area had been increased over the gap of five years from 2010 to 2015.

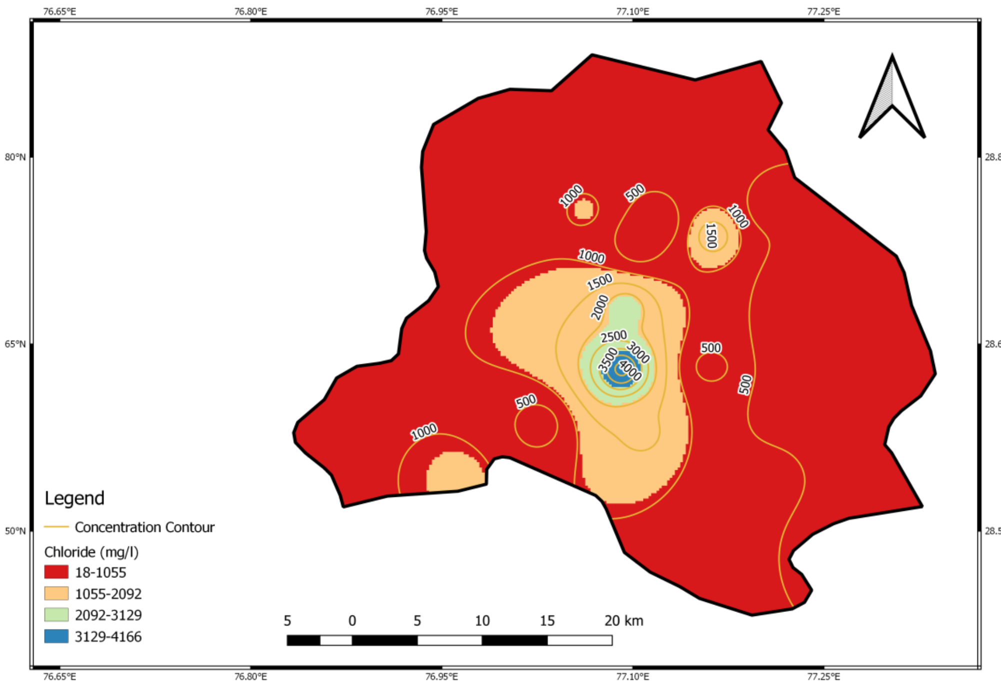

Fig 4.15: Spatial Distribution of Chloride in groundwater in NCT Delhi in 2010

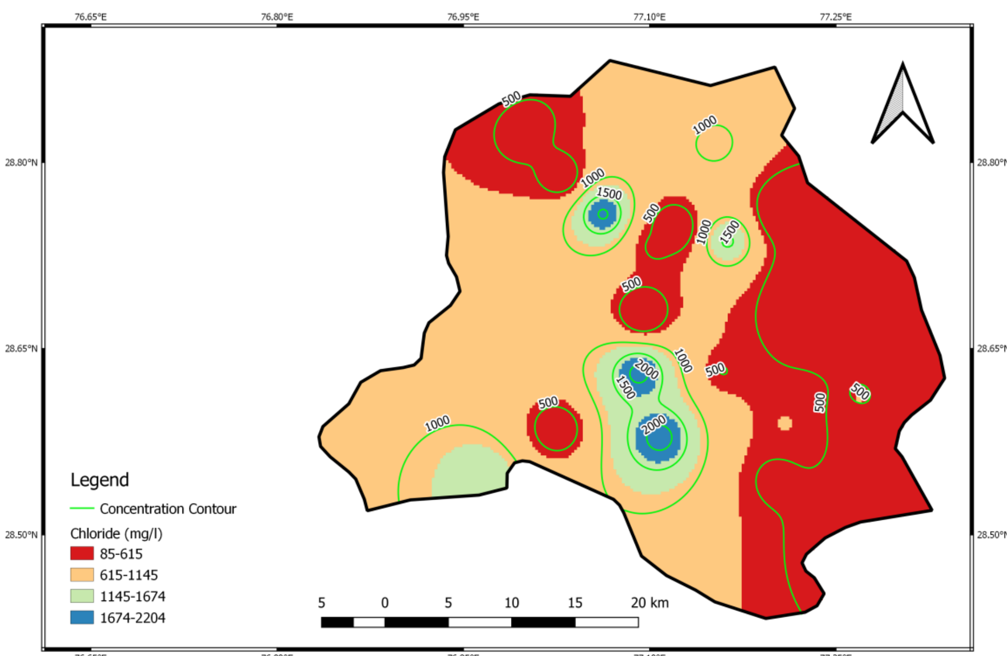

Fig 4.16: Spatial Distribution of Chloride in groundwater in NCT Delhi in 2015

4.1.9 Nitrate

The acceptable limit of nitrate in drinking water as set by BIS (2012) is 45 mg/l with no further relaxation. In year 2010, the nitrate content in the groundwater of the study area varied from zero mg/l in Hauz Khas to 533 mg/l in India Gate. The spatial distribution of nitrate in groundwater of the study area is shown in fig 4.17. It shows that New Delhi, West Delhi and parts of South West Delhi had higher content of nitrate in groundwater.

The concentration of nitrate in study area in year 2015 was varying from 1.61 mg/l in Burarai to 710 mg/l in Hauz Khas. The spatial distribution of nitrate in groundwater in NCT Delhi is shown in fig 4.18. Najafgarh drain that runs from South west part of the city carries enormous amount of pollutant load and seepages from it might contribute to nitrate in groundwater. It can be concluded that South, South west and New Delhi areas had high content of nitrate in groundwater.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the nitrate content of 12 monitored stations i.e Hauz Khas, Bakoli, Akshardham Temple , Auchandi, Barwala, Ushmanpur, Tagore garden , ISBT (Kashmere Gate), Delhi College of Engineering, Rohini Sector-11, Chilla Regulator and Daulatpur had increased while 16 monitored stations i.e Lodhi Garden, India Gate, Wazirabad , PUSA, Asola, Safdarjung tomb, Balswa lake, Janakpuri, Majanu ka Tila, Burarai , Bawana, Singhola, Dwarka Sector-16, Nizamuddin Bridge-2 , Hareoli, and Peera Garhi had recorded lesser nitrate content. So overall the nitrate content of the study area had been decreased over the gap of five years from 2010 to 2015.

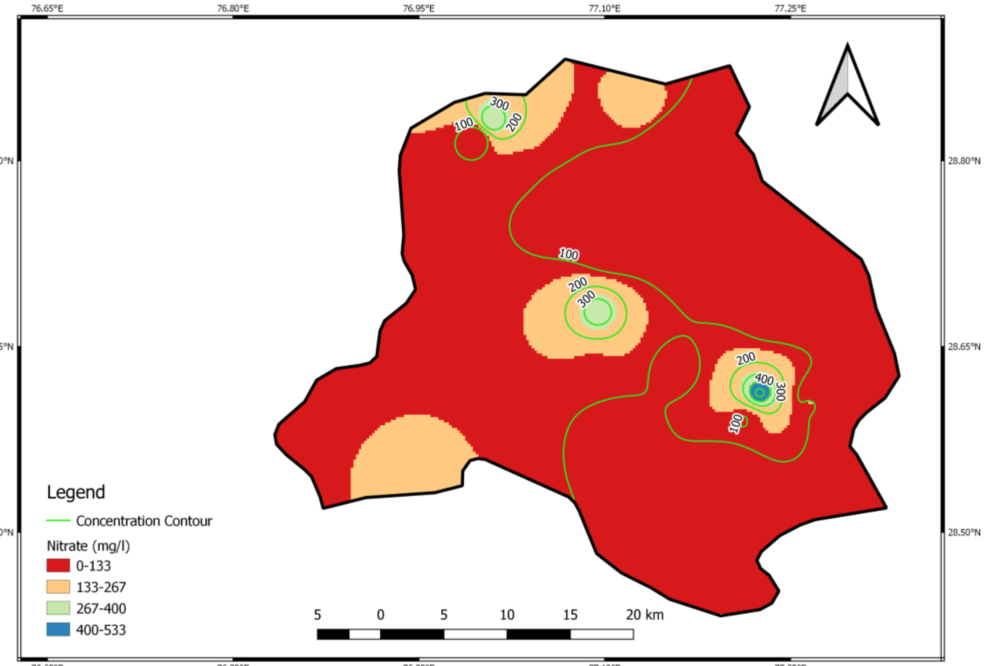

Fig 4.17: Spatial Distribution of Nitrate in groundwater in NCT Delhi in 2010

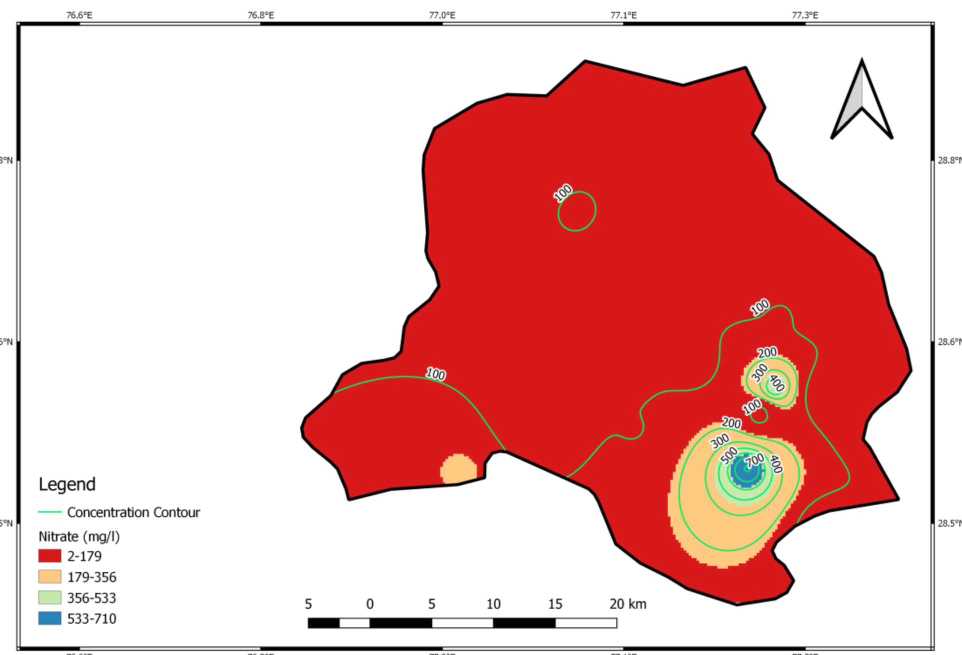

Fig 4.18: Spatial Distribution of Nitrate in groundwater in NCT Delhi in 2015

4.1.10 Fluoride

The desirable and permissible limit of fluoride in drinking water is 1.0 mg/l and 1.5 mg/l as per BIS (2012) respectively. In year 2010, the fluoride content in the groundwater of the study area varied from 0.12 mg/l in Barwala to 3.65 mg/l in Delhi College of Engineering. The spatial distribution of fluoride in groundwater of the study area is shown in fig 4.19. It shows that except five groundwater monitoring stations namely Wazirabad, Auchandi, Delhi College of Engineering, Rohini sector-11 and Dwarka Sector-16 , all other monitoring stations had fluoride within the permissible limit in groundwater.

In year 2015, the concentration of fluoride in groundwater in the study area varied from 0.2 mg/l in Barwala to 3.60 mg/l in Delhi College of Engineering. The data indicate that Southwest and most of the Northwest districts were the highly affected. The spatial distribution of fluoride in groundwater in NCT Delhi is shown in fig 4.20.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the fluoride content of 17 monitored stations i.e Singhola, Balswa lake, Bawana, Tagore garden , Wazirabad , Janakpuri, Bakoli, Peera Garhi, Barwala, Chilla Regulator ISBT (Kashmere Gate), Safdarjung tomb, Burarai , India Gate, PUSA, Hauz Khas and Asola had increased while 11 monitored stations i.e Delhi College of Engineering, Rohini Sector-11,Lodhi Garden, Akshardham Temple , Auchandi, Daulatpur, Hareoli, Ushmanpur, Nizamuddin Bridge-2 , Majanu ka Tila and Dwarka Sector-16 had recorded lesser fluoride content. So overall the fluoride content of the study area had been increased over the gap of five years from 2010 to 2015.

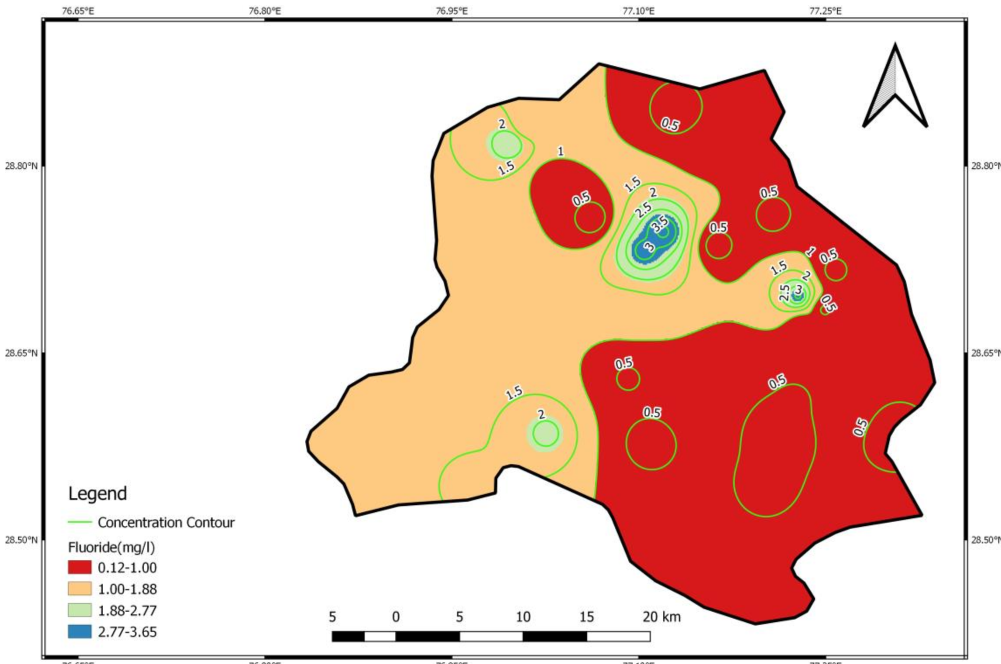

Fig 4.19: Spatial Distribution of Fluoride in groundwater in NCT Delhi in 2010

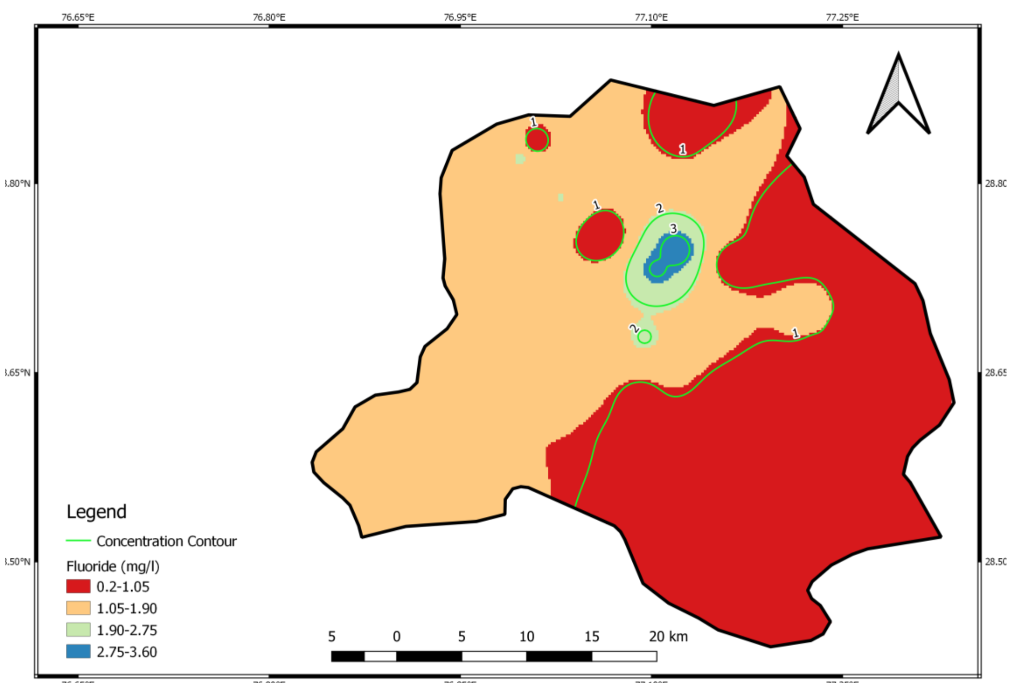

Fig 4.20: Spatial Distribution of Fluoride in groundwater in NCT Delhi in 2015

4.1.11 Sulphates

The desirable and the permissible limit of sulphate in drinking water as per BIS (2012) are 200 mg/l and 400 mg/l respectively. . In year 2010, the sulphate content in the groundwater of the study area varied from zero mg/l in Majanu ka Tila and Nizamuddin Bridge-2 to 3270 mg/l in Tagore Garden.The spatial distribution of sulphate in groundwater of the study area is shown in fig 4.21. It shows that West Delhi monitoring stations had higher content of sulphate in the groundwater.

In year 2015, the concentration of sulphate in groundwater in the study area varied from 23 mg/l in Chilla Regulator to 3852 mg/l in Tagore Garden. The spatial distribution of sulphate in groundwater in NCT Delhi is shown in fig 4.22. It shows parts of South West, North West and West Delhi district had higher content of sulphate in groundwater.

After comparing the results for the year 2010 and 2015, it can be concluded that over the five years gap , the sulphate content of 20 monitored stations i.e Nizamuddin Bridge-2 , Majanu ka Tila, Balswa lake, ISBT (Kashmere Gate), Daulatpur, Barwala, Hareoli, Rohini Sector-11, Janakpuri, Delhi College of Engineering, India Gate, Singhola, Lodhi Garden, Ushmanpur, Bakoli, Asola, PUSA, Dwarka Sector-16, Tagore garden and Bawana, , Burarai , had increased while 07 monitored stations i.e, Akshardham Temple , Hauz Khas, Safdarjung tomb, Wazirabad , Chilla Regulator, Peera Garhi and Auchandi, had recorded lesser sulphate content. Burarai was the only station which had same content of sulphate in both the years. So overall the sulphate content of the study area had been increased over the gap of five years from 2010 to 2015.

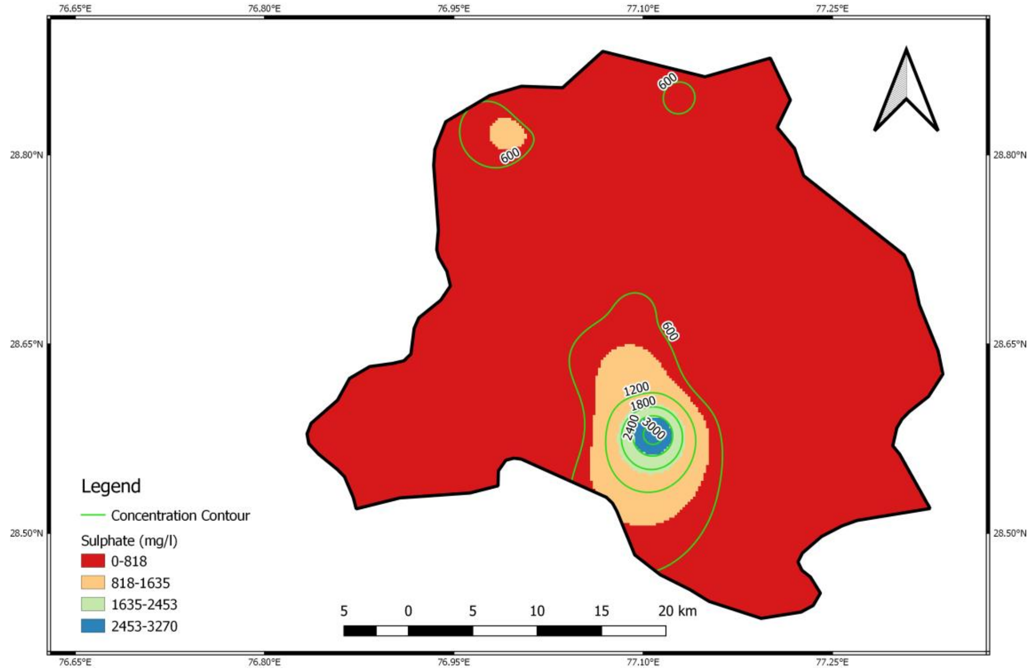

Fig 4.21: Spatial Distribution of Sulphate in groundwater in NCT Delhi in 2010

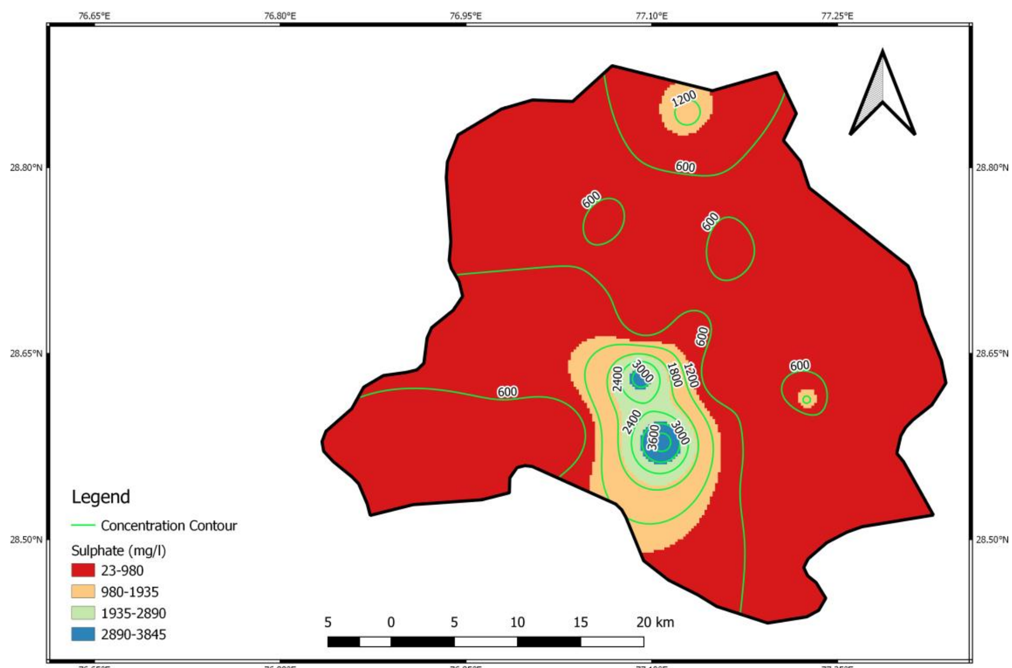

Fig 4.22: Spatial Distribution of Sulphate in groundwater in NCT Delhi in 2015

4.2. IRRIGATION WATER QUALITY

The parameters considered for the assessing the groundwater quality for irrigation purpose includes Salinity hazard, Sodium Adsorption Ratio (SAR), Permeability Index (PI) and Percent Sodium (Na%). These parameters are indirectly calculated from the available concentration of other parameters. The computed values of irrigation water quality parameters are given in table A3.1 and A3.2 for the years 2010 and 2015 respectively. The variation of the concentration of these parameters in groundwater in the study area during the year 2010 and 2015, along with the comparison of water suitability for irrigation over these years is discussed in detail below.

4.2.1 Salinity Hazard

Salinity Hazard is measured in terms of electrical conductivity (EC). The total content of salt in the water determines its salinity. In general soil and plants are prone to high saline water and thus productivity gets affected. In year 2010, the electrical conductivity in the groundwater of the study area varied from 562 µS/cm in Rohini Sector-11 to 13800 µS/cm in Janakpuri. 46.4% of the groundwater was lying in the range of doubtful to unsuitable category while remaining 53.6% of the groundwater is suitable for irrigation purpose. The spatial distribution of salinity in the groundwater of the NCT Delhi for the year 2010 is shown in fig 4.23.

In 2015, the electrical conductivity in the study area varied from 529.4 µS/cm in Burari (North Delhi) to 14470 µS/cm in Tagore Garden (South Delhi). 32.2% of the groundwater was lying in the range of doubtful to unsuitable category while remaining 67.8% of the groundwater is suitable for irrigation purpose. The spatial distribution of salinity in the groundwater of the NCT Delhi for the year 2015 is shown in fig 4.24.

On comparing the results for both the year 2010 and 2015, it can be concluded that in year 2015 the saline content of the groundwater had been decreased and hence irrigation water quality of the area had been improved over the gap of five years.

Table 4.1: Classification of Groundwater quality for Irrigation based on Salinity Hazard

Water Quality	**Range of Electrical Conductivity(μS/cm)**	**No. of Samples**		**Percent (%)**	
		2010 year	**2015 year**	**2010 year**	**2015 year**
Excellent	<1500	11	09	39.3	32.1
Good	1500-3000	04	10	14.3	35.7
Doubtful	3000-6000	09	05	32.1	17.9
Unsuitable	>6000	04	04	14.3	14.3

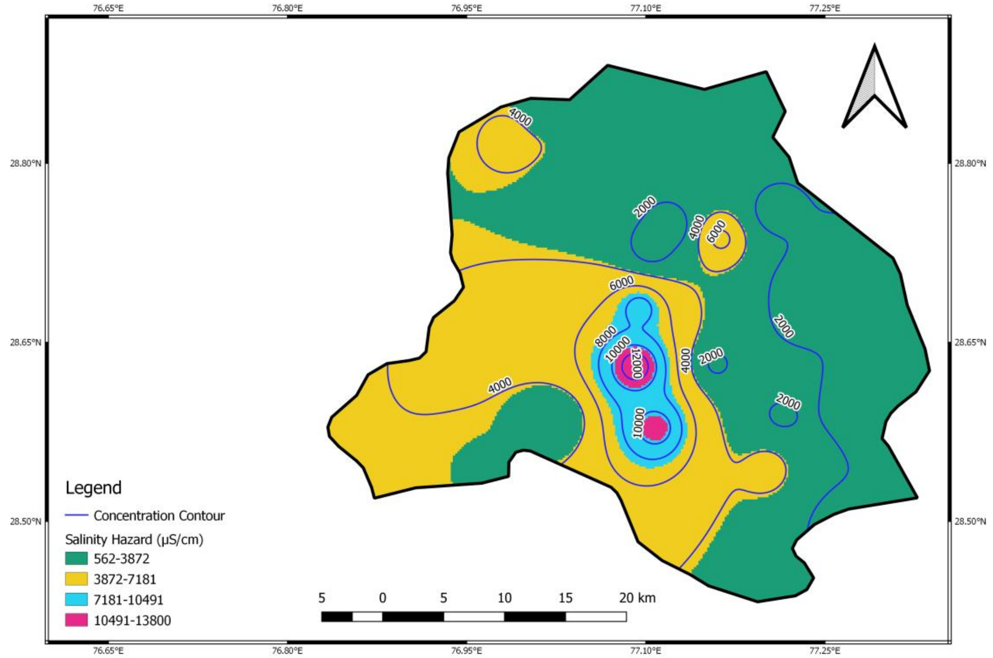

Fig 4.23: Spatial Distribution of Salinity Hazard in groundwater in NCT Delhi in 2010

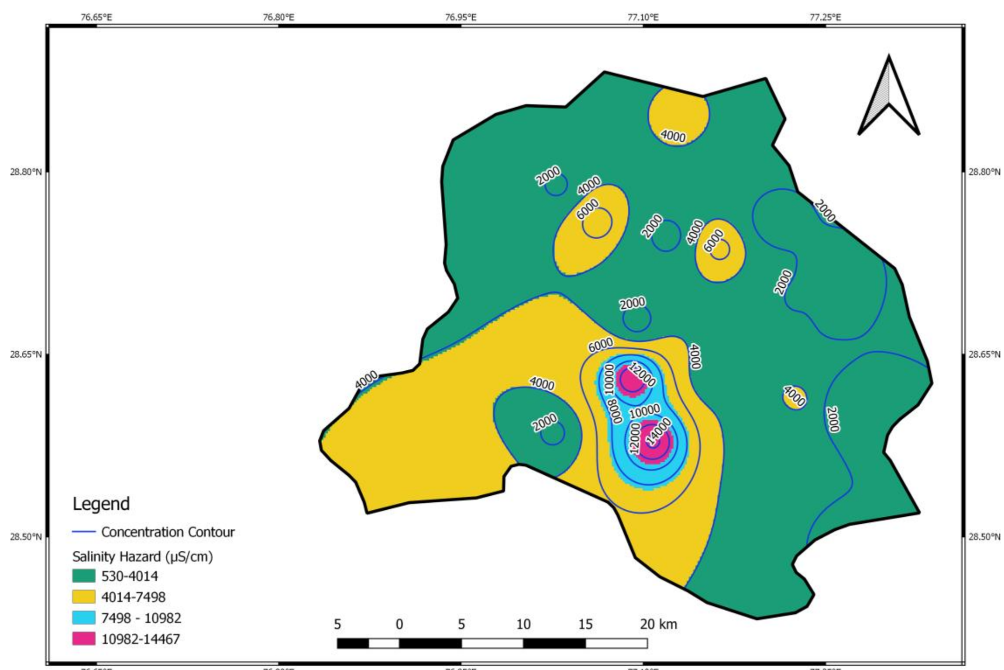

Fig 4.24: Spatial Distribution of Salinity Hazard in groundwater in NCT Delhi in 2015

4.2.2 Sodium Adsorption Ratio

In 2010, Sodium Adsorption Ratio (SAR) in the study area varied from 0.35 in Barwala to 15.68 in Tagore Garden. All the groundwater monitoring stations were lying in the “excellent to good” water quality category. Hence, the study area was suitable for irrigation in terms of SAR. The spatial distribution of SAR in the groundwater of study area for the year 2010 is shown in fig 4.25.

In year 2015, SAR varied from 0.9 in Chilla Regulator to 26.08 in Tagore Garden in the study area. 92.8% of sampling stations were having SAR in the excellent to good range, while only 7.2 % were having SAR greater than required. The spatial distribution of SAR is shown in fig 4.26. It shows that only 2 sampling stations namely Tagore Garden and PUSA were having high SAR and therefore were unsuitable for irrigation purpose.

On comparing the results for both the year 2010 and 2015, it can be concluded that in year 2015 the SAR of the groundwater had been increased and hence irrigation water quality of the area had been degraded over the gap of five years.

Table 4.2: Classification of groundwater for Irrigation based on SAR (Todd,1959)

Water Quality	Range of SAR	No. of Samples		Percent(%)	
		2010 year	2015 year	2010 year	2015 year
Excellent	< 10	23	24	82.1	85.7
Good	10-18	05	02	17.9	7.1
Doubtful	18-26	00	01	00	3.6
Unsuitable	>26	00	01	00	3.6

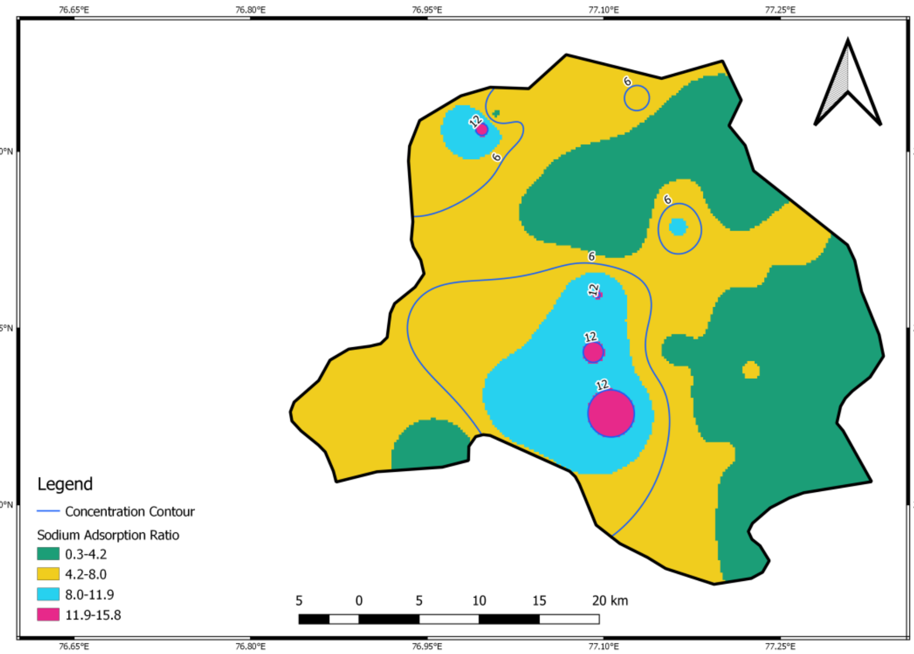

Fig 4.25: Spatial Distribution of SAR in groundwater in NCT Delhi in 2010

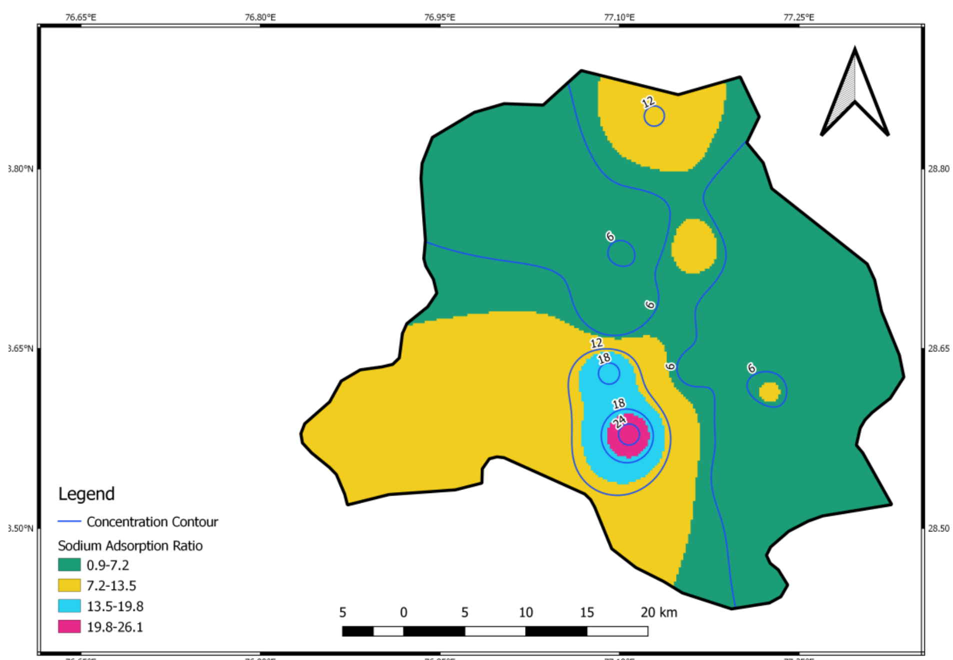

Fig 4.26: Spatial Distribution of SAR in groundwater in NCT Delhi in 2015

4.2.3 Permeability Index

In year 2010, the Permeability Index (PI) in the study area varied from 7.65% in Barwala to 95.75% in Majanu ka Tila. Except Barwala, all other monitoring stations were lying in the excellent (Class I) to good (Class II) category of irrigation water, hence groundwater in these area could be used for irrigation purpose. The spatial distribution of Permeability index in the study area is shown in fig 4.27.

PI varied in the study area in 2015 year from 26.64% in Chilla Regulator to 90.90% in Dwarka sector-16. It can be concluded that all the sampling stations were lying in the excellent (Class I) to good (Class II) category of irrigation water, hence groundwater in these area could be used for irrigation purpose. The spatial distribution of Permeability index in the study area is shown in fig 4.28.

It can be concluded after comparing the results for the year 2010 and 2015 that PI has improved over the gap of five years .

Table 4.3: Classification of Groundwater for Irrigation based on PI (Doneen, 1964)

Class	Description of Water Quality	Range of Permeability Index (PI)	No. of Samples		Percent (%)	
			2010 year	2015 year	2010 year	2015 year
I	Excellent	>75%	03	04	10.7	14.3
II	Good	25%-75%	24	24	85.7	85.7
III	Unsuitable	<25%	01	00	3.6	00

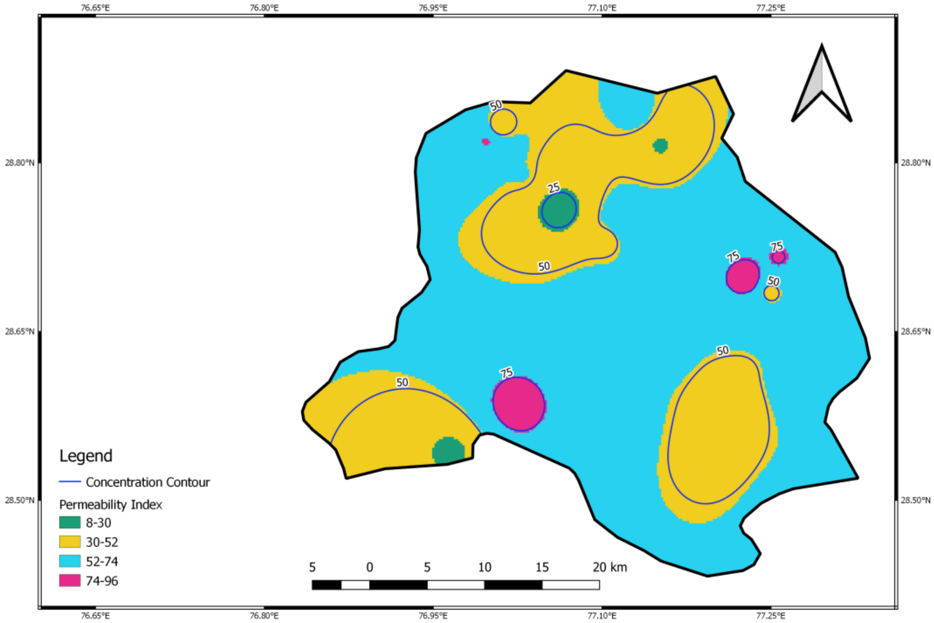

Fig 4.27: Spatial Distribution of PI in groundwater in NCT Delhi in 2010

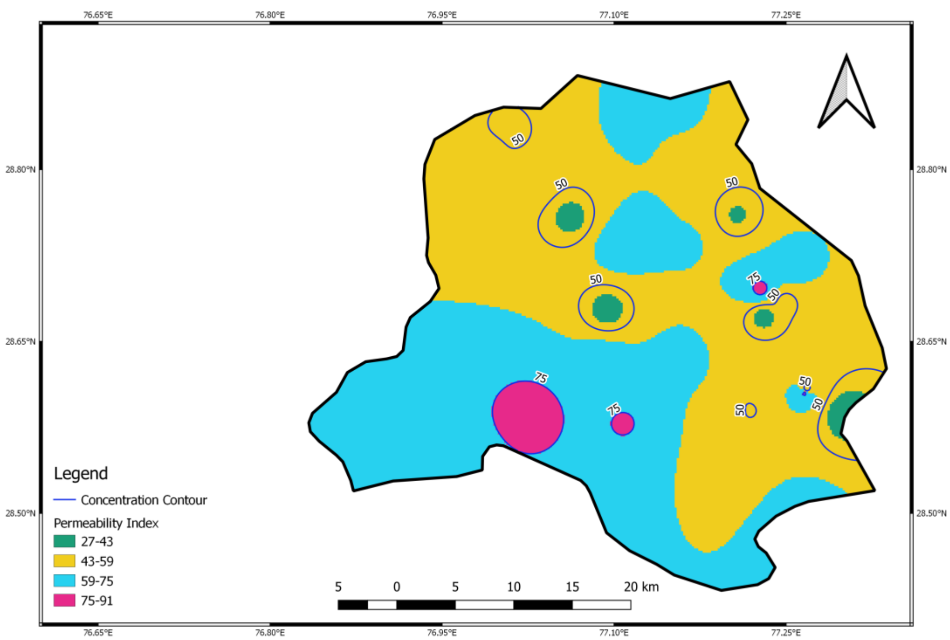

Fig 4.28: Spatial Distribution of PI in groundwater in NCT Delhi in 2015

4.2.4 Percent Sodium

In year 2010, the percent sodium varied from 4.05% in Barwala to 76.19% in Dwarka Sector-16. 42.8% of the monitoring stations were having excellent to good quality of irrigation water, 39.3 % were having permissible quality while on;y 17.9% were lying in the doubtful category. The spatial distribution of percent sodium in the study area for the year 2010 is shown in fig 4.29.

Variation of percent sodium in year 2015 in the study area ranges from 24% in Peera Garhi to 75.98% in Tagore Garden. According to the classification done in table 4.4, it can be concluded that only 28.6% of sampling station was having excellent to good quality of irrigation water, 46.4% were having permissible quality while only 25% were lying in the doubtful category. The spatial distribution of Na% in the study area for year 2015 is shown in fig 4.30.

After comparing the results of percent sodium (Na%) for years 2010 and 2015, it can be concluded that in year 2015 the groundwater had higher values of percent sodium and thus it is less suitable for irrigation as compared to groundwater in year 2010.

Table 4.4: Classification of Groundwater for Irrigation based on Na% (Wilcox, 1955)

Water Quality	Percent Sodium	No. of samples		Percent (%)	
		2010 year	2015 year	2010 year	2015 year
Excellent	<20	03	00	10.7	00
Good	20-40	09	08	32.1	28.6
Permissible	40-60	11	13	39.3	46.4
Doubtful	60-80	05	07	17.9	25
Unsuitable	>80	00	00	00	00

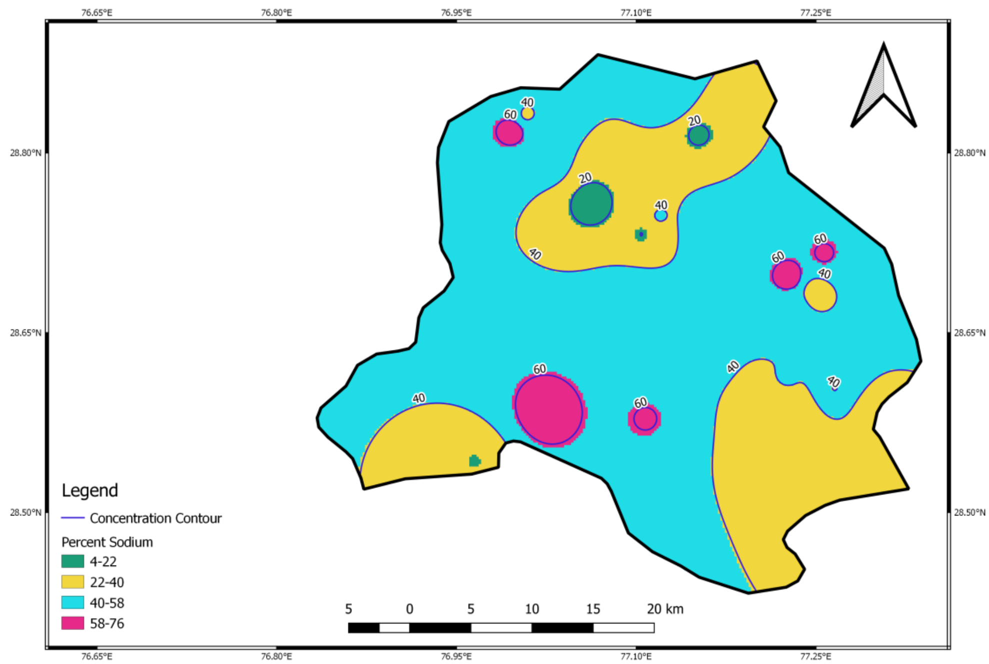

Fig 4.29: Spatial Distribution of Percent Sodium in groundwater in NCT Delhi in 2010

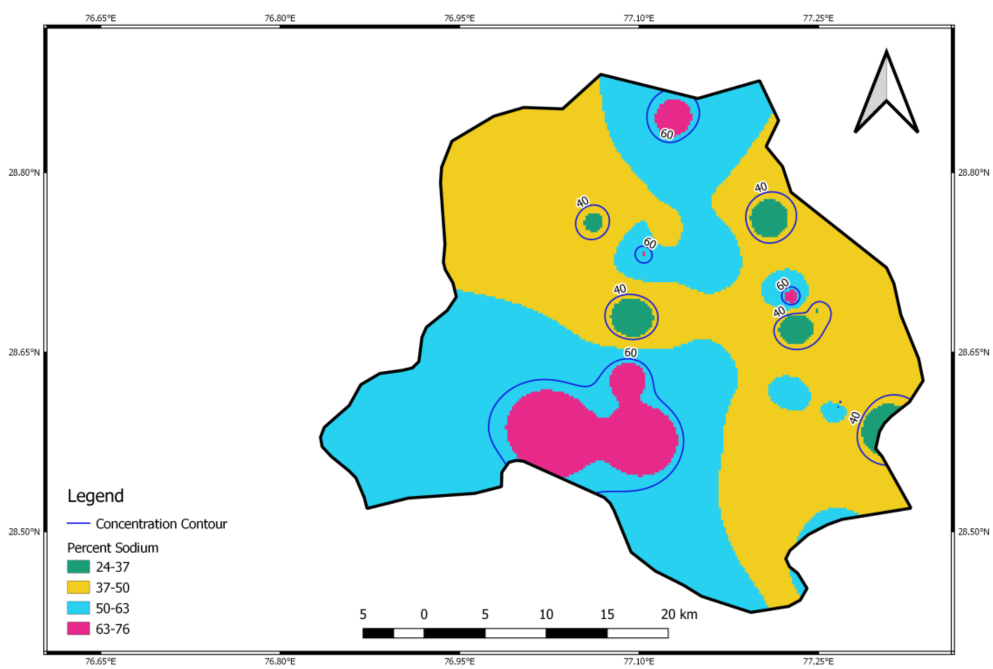

Fig 4.30: Spatial Distribution of Percent Sodium in groundwater in NCT Delhi in 2015

4.3. WATER QUALITY INDEX FOR DRINKING PURPOSE

In this study, an attempt has been made to determine the suitability of groundwater for drinking purpose based on the computed Water Quality Index (WQI) . The groundwater data for the NCT Delhi for the years 2010 and 2015 has been taken from Central Ground Water Board (CGWB). Water quality index is developed using 11 different water quality parameters and the standards and the permissible limit prescribed by BIS (2012) using the weighted arithmetic index method (Brown et al., 1970) . The computed WQI values are given in table A4. The groundwater quality can be categorized from “excellent” to “water unsuitable for drinking” on the basis of these computed WQI values. Table 4.5 shows the number of samples and their percentages falling under each category.

For the year 2010, the computed water quality index values of the study area varied from 45.24 of Chilla Regulator to 674.43 of Janakpuri. Only one groundwater monitoring station namely Chilla Regulator had excellent water quality. Majority of the monitoring stations i.e 46.4% were having “poor” to “very poor” water quality. Groundwater from 21.4% of the monitoring stations was unsuitable for drinking purpose. Overall New Delhi, parts of North West Delhi, South West Delhi and West Delhi had poor to unsuitable water quality. The spatial distribution of WQI for the year 2010 is shown in fig 4.31.

For the year 2015, the computed water quality index values of the study area varied from 45.71 of Burarai to 578.39 of Tagore Garden. It can be seen from table 4.5 that only 2 monitoring station out of the 28 sampling stations had excellent water quality.

These stations were Burarai and Chilla Regulator. Majority of the sampling stations i.e 42.9% were having poor groundwater quality. They include areas from East Delhi, New Delhi, North Delhi and North East Delhi. Groundwater from 25% of the monitoring stations was unsuitable for drinking purpose. In these parts, the quality of groundwater might be improved by the infiltration of fresh water during the monsoon. The spatial distribution of WQI in the study area is shown in fig 4.32.

Table 4.5: Groundwater quality classification based on WQI

WQI	Water Quality	No. of Samples		Percent (%)	
		2010 year	**2015 year**	**2010 year**	**2015 year**
<50	Excellent	01	02	3.6	7.1
50-100	Good	08	04	28.6	14.3
100-200	Poor	07	12	25	42.9
200-300	Very Poor	06	03	21.4	10.7
>300	Unsuitable	06	07	21.4	25

After comparing the results for years 2010 and 2015, it can be concluded that in year 2015, water quality index of 10 groundwater monitoring stations had decreased thus the water quality of these stations namely Peera Garhi, Nizamuddin Bridge-2, Bawana, Hareoli, Auchandi, Burarai, Dwarka Sector-16, Janakpuri, Balswa Lake and Singhola had been increased over a span of five years . While water quality index of 18 grundwater monitoring stations had increased thus the groundwater quality of these stations namely Daulatpur, Tagore Garden, Chilla Regulator, Safdarjung tomb, Lodhi garden, Asola, Wazirabad, Majanu ka Tila, India Gate, PUSA, Delhi college of Engineering, Ushmanpur, Hauz Khas, Rohini Sector-11. Bakoli, Barwala, akshardham Temple and ISBT(Kashmere Gate) had been deteriorated over the span of five years.

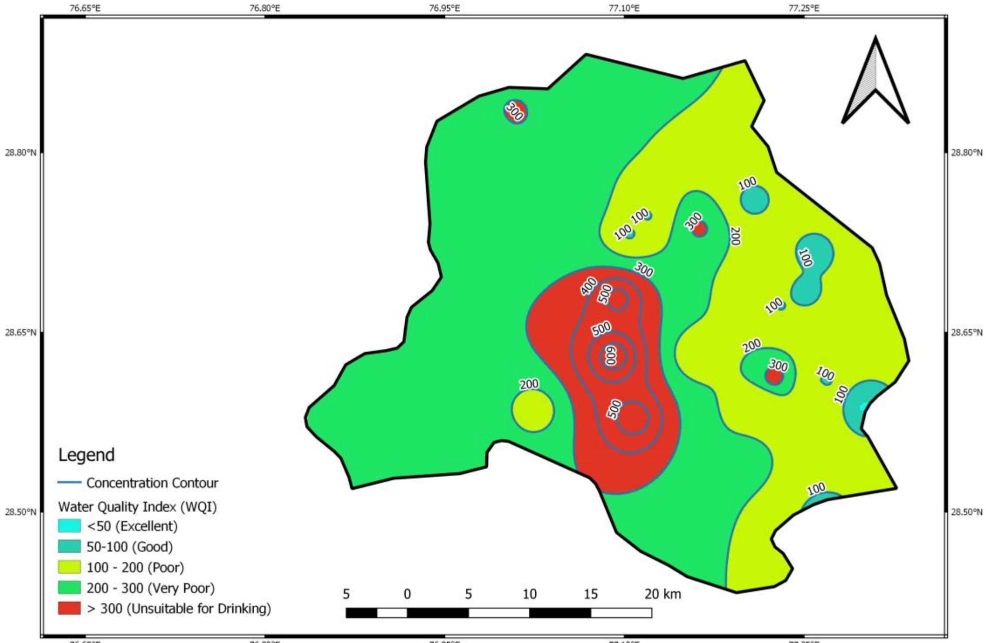

Fig 4.31: Spatial Distribution of Water Quality Index of NCT Delhi in 2010

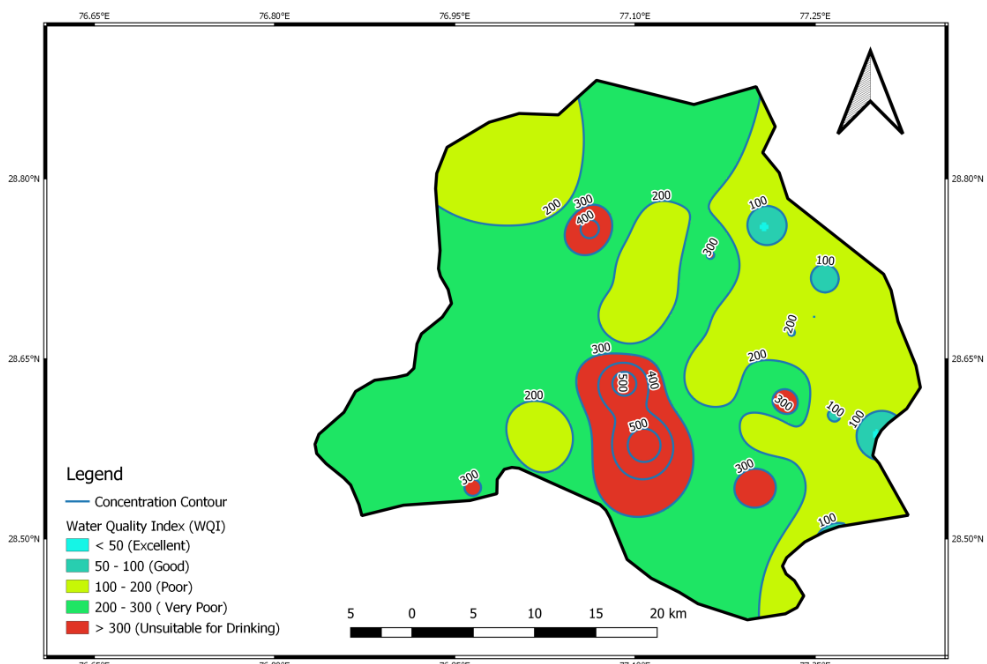

Fig 4.32: Spatial Distribution of Water Quality Index of NCT Delhi in 2015

CHAPTER 5

CONCLUSIONS

Based on the findings of the work undertaken for the assessment of the groundwater quality, the following conclusions can be inferred:

i. The pH of the NCT Delhi in 2010 was found to be slightly neutral to brackish in nature. Except groundwater monitoring stations Rohini Sector-11 and Dwarka Sector-16, the pH of all others stations were within the permissible limit.

   While the pH of the study area in 2015 was found to be brackish in nature. pH values lies within the permissible limit except in few locations. The pH > 8.5 was found to be in Majanu Ka Tila, Delhi College of Engineering, Rohini Sec-11 and Dwarka Sec-16.

ii. The total hardness of the groundwater in the study area during 2010 as well as 2015 was found to be on higher side in areas like North Western part of the city. Overall it can be concluded that over the span of five years from 2010 to 2015, the total hardness in the groundwater had decreased.

iii. The concentration of total alkalinity of the study area was found to be within the permissible limit i.e less than 600 mg/l in both years 2010 and 2015. The presence of hydroxides, carbonates and bicarbonates in the water are the main cause of alkalinity in water. While comparing the total alkalinity content in groundwater for both the years, it can be concluded that the total alkalinity content had decreased over the span of five years.

iv. The concentration of calcium in groundwater during year 2010 was found to be on higher side in West and parts of South West Delhi. While in 2015, majority of groundwater monitoring stations had calcium content within the permissible range. So it can be concluded that the calcium content of the groundwater had decreased from 2010 to 2015.

v. The concentration of magnesium in groundwater during year 2010 was found to be on higher side in parts of SouthWest, North West and West Delhi. While during year 2015, the overall magnesium content in groundwater had increased as compared to year 2010 and was found to be more in East and parts North West Delhi.

vi. The overall concentration of potassium in groundwater had increased during year 2015 as compared to year 2010. But the concentration of potassium in stations namely Singhola, Nizamuddin Bridge-2 and Lodhi garden had recorded same content of potassium in groundwater in both years.

vii. The concentrations of sodium, chloride, fluoride and sulphate in groundwater had increased during 2015 as compared to year 2010. The data shows that the North West district of Delhi had high content of these ions in groundwater and thus results in poor quality of water.

viii. The overall concentration of nitrate in groundwater had decreased over the span of five years from 2010 to 2015. The worst affected parts include North West, New Delhi and South districts of the study area. The increased concentration of nitrate might be due to excessive use of nitrogenous fertilizers or disposal of sewage into the groundwater. The Najafgarh drain of the city that runs from the

Southwest part of the city might contribute to higher concentration of nitrate in groundwater.

ix. Irrigation water quality was lying under “excellent” to “ permissible” category in the majority of areas of the NCT Delhi on the basis of parameters namely salinity hazard, sodium Adsorption ratio (SAR), permeability index (PI) and percent sodium (Na%) during the years 2010 and 2015. Hence, the groundwater of the NCT Delhi could be used for irrigation purpose.

x. In year 2010, the WQI shows that majority of groundwater (67.8%) in NCT Delhi was lying in the category of “poor” to “unsuitable for drinking”. These areas were New Delhi, parts of North West, South West and West Delhi. Only one groundwater monitoring station namely Chilla Regulator was having excellent water quality in year 2010.While in 2015, WQI shows that majority of water in NCT Delhi (78.6% of the water sources) was lying in the category of “poor” to “unsuitable for drinking”. The areas with groundwater not fit for human consumption includes East Delhi, New Delhi, North Delhi and North East Delhi districts. Only 2 locations Burarai and Chilla Regulator were having excellent water quality based on WQI.

xi. It can be concluded that overall the quality of groundwater of NCT Delhi from 2010 to 2015 had been deteriorated. The reasons for this might be speedup industrialization, urbanization, increase in population and in differentiate use of groundwater resources.

APPENDICES

Appendix 1

Table A1: Locations of Groundwater Monitoring Stations

S.No	Stations	Latitude	Longitude
1	Akshardham Temple	28.6083	77.2677
2	Chilla Regulator	28.5872	77.3014
3	Nizamuddin Bridge-2	28.6047	77.2661
4	India gate	28.6125	77.225
5	Lodhi Garden	28.5903	77.2164
6	Safdarjung tomb	28.5903	77.2125
7	Burarai	28.76	77.2075
8	ISBT (Kashmiri Gate)	28.6722	77.2306
9	Majanu Ka Tila	28.6958	77.2278
10	Ushmanpur	28.6847	77.2492
11	Wazirabad	28.7158	77.2567
12	Auchandi	28.8194	76.9972
13	Bakoli	28.8153	77.1517
14	Balswa Lake	28.7364	77.1628
15	Barwala	28.7583	77.0625
16	Bawana	28.7889	77.0292
17	Delhi College of Engineering	28.7472	77.1194
18	Hareoli	28.8319	77.0083
19	Rohini Sector – 11	28.7322	77.1044

20	Singhola	28.8433	77.1294
21	Asola	28.4958	77.2667
22	Hauz Khas	28.5453	77.2022
23	Daulatpur	28.5431	76.9653
24	Dwarka Sec-16	28.5856	77.0261
25	PUSA	28.6319	77.1594
26	Tagore Garden	28.5786	77.1081
27	Janakpuri	28.63	77.0914
28	Peera Garhi	28.6781	77.0947

Appendix 2

Table A2.1: Groundwater quality parameters for drinking purpose for the year 2010

S.no	Locations	pH	Ca	Cl	F	K	Mg	Na	Nitrate	SO_4	Total Hardness	Total Alkalinity
Units			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Akshardham Temple	7.22	38	113	0.89	50	41	131	1.1	260	264	180.33
2	Chilla Regulator	7.71	55	62	0.19	6.9	18	41	4	45	211	172.13
3	Nizamuddin Bridge-2	7.01	133	189	0.55	10	23	109	145	0	428	311.48
4	India gate	7.91	136	486	0.4	12	158	340	533	480	989	98.36
5	Lodhi Garden	7.69	136	365	0.37	1	77	95	106	70	656	163.93
6	Safdarjung tomb	6.82	127	406	0.16	2.5	104	107	87	100	745	0
7	Burarai	8.31	95	199	0.29	4.5	25.7	108	3.7	85	343	213.11
8	ISBT (Kashmiri Gate)	7.76	82	103	0.54	34	21	96	73	65	290	270.49
9	Majanu Ka Tila	8.17	51	110	3.08	69	7.8	172	91	0	159	377.05
10	Ushmanpur	7.21	99	138	0.44	5.1	38	62	6.4	130	406	213.11

11	Wazirabad	7.73	27	213	0.34	5	42.7	189	11	180	243	163.93
12	Auchandi	8.23	70	653	2.46	4	156	850	15	1200	818	484.43
13	Bakoli	7.44	116	684	0.6	5.1	115	65	1	340	762	229.51
14	Balswa Lake	8.13	300	1889	0.2	8	200	805	53	48	1573	557.38
15	Barwala	8.13	435	1108	0.12	1.9	173	34	55	150	1800	98.36
16	Bawana	8.21	150	822	0.7	2	140	370	105	218	950	278.69
17	Delhi College of Engineering	7.72	45	18	3.65	25	18	45	15	45	219	213.11
18	Hareoli	8.18	123	716	1.07	2	189	300	385	110	1066	254.1
19	Rohini Sector – 11	8.55	49	32	3.22	2	26	25	20	80	229	139.89
20	Singhola	8.83	51	569	0.15	2	182	445	196	680	876	180.87
21	Asola Pz	7.62	6.4	74	0.68	1.6	49	52	23	26	217	180.33
22	Hauz Khas	6.8	285	750	0.35	1	237	414	0	448	1689	188.52
23	Daulatpur	7.75	209	1122	1.6	12	236	184	175	24	1494	147.54

24	Dwarka Sec-16	8.95	27	225	2.12	2	44	368	112	62	248	524.02
25	PUSA	7.86	94	358	0.79	4	56	178	67	50	553	0
26	Tagore Garden	8.25	482	1609	0.24	12	260	1725	51	3270	2275	278.69
27	Janakpuri	7.54	655	4176	0.41	25	418	1692	110	1050	3358	213.11
28	Peera Garhi	8.31	275	2418	1.08	20	318	1242	360	700	1996	286.89

Table A2.2: Groundwater quality parameters for drinking purpose for the year 2015

S.no	Locations	pH	Ca	Cl	F	K	Mg	Na	Nitrate	SO_4	Total Hardness	Total Alkalinity
Units			mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	Akshardham Temple	8.32	50	754	0.75	7	148	210	4.65	187	742	54.72
2	Chilla Regulator	8.14	27	158	0.31	8	38	31	4.6	23	225	2.3
3	Nizamuddin Bridge-2	8.43	22	134	0.35	10	31	126	37.5	75	185	168.38
4	India gate	7.84	115	589	0.46	26	185	640	499	1261	1058	37.11
5	Lodhi Garden	7.82	98	499	0.34	1	106	209	100	134	687	108.03
6	Safdarjung tomb	7.96	79	688	0.21	4	99	254	62.4	66	611	115.57
7	Burarai	8.04	22	85	0.34	11	35	32	1.61	85	202	32.84
8	ISBT (Kashmiri Gate)	8.12	136	153	0.87	10	144	132	125	451	942	401.48
9	Majanu Ka Tila	8.56	21	126	1.85	110	56	207	52.7	143	288	432.43
10	Ushmanpur	8.34	28	136	0.29	52	74	71	12.9	247	379	180.32
11	Wazirabad	8.37	33	101	0.73	9	49	107	8.96	117	288	255.82

12	Auchandi	8.39	37	435	1.97	3	127	221	38.3	332	622	188.04
13	Bakoli	8.13	165	1134	1.23	8	172	586	16	617	1128	123.03
14	Balswa Lake	7.79	203	1564	0.59	14	213	897	35.4	909	1395	145.57
15	Barwala	7.55	368	2056	0.2	7	387	623	132	713	2536	60.2
16	Bawana	8.1	58	318	1.91	6	68	170	38.5	231	426	150.82
17	Delhi College of Engineering	8.77	41	150	3.6	8	53	126	19.5	135	323	247.19
18	Hareoli	8.21	76	462	0.77	10	164	271	56.3	489	877	146.23
19	Rohini Sector – 11	8.73	18	458	3.13	13	81	294	23.6	272	383	121.44
20	Singhola	7.93	128	848	0.53	2	131	860	62.9	1320	866	20.15
21	Asola Pz	8.35	28	120	0.72	3	32	106	16.5	46	204	166.89
22	Hauz Khas	7.95	139	411	0.38	2	107	303	710	307	794	103.2
23	Daulatpur	7.91	140	1430	1.24	35	190	708	192	148	1142	306.8
24	Dwarka Sec-16	8.72	8	288	1.05	6	50	320	34.2	88	226	441.45

25	PUSA	7.68	53	494	0.89	1	99	280	51.7	71	544	381.31
26	Tagore Garden	7.94	412	2204	0.54	6	162	2477	97.5	3852	1706	176.07
27	Janakpuri	7.84	513	2142	0.85	7	193	2065	68	3224	2088	194.43
28	Peera Garhi	7.94	62	144	2.04	10	70	59	48.7	200	448	105

Appendix 3

Table A3.1: Groundwater quality parameters for Irrigation purpose in year 2010

S.No	Locations	Salinity Hazard (EC) (µS/cm)	SAR	PI	Na %
1	Akshardham Temple	1100	3.49	68.97	56.76
2	Chilla Regulator	586	1.22	60.31	31.56
3	Nizamuddin Bridge-2	1250	2.29	54.38	36.83
4	India gate	3480	4.68	46.58	43.05
5	Lodhi Garden	1670	1.61	34.25	23.92
6	Safdarjung tomb	1810	1.70	34.55	23.90
7	Burarai	1040	2.53	58.31	41.09
8	ISBT (Kashmiri Gate)	1030	2.44	64.84	46.31
9	Majanu Ka Tila	1170	5.91	95.75	74.29
10	Ushmanpur	1063	1.34	44.03	25.83
11	Wazirabad	1300	5.25	76.40	62.97
12	Auchandi	4830	12.87	74.96	69.19
13	Bakoli	3120	1.02	27.29	16.12
14	Balswa Lake	6580	8.80	57.51	52.65
15	Barwala	3600	0.35	7.65	4.05
16	Bawana	3310	5.20	52.33	45.71
17	Delhi College of Engineering	599	1.43	70.46	40.92
18	Hareoli	3330	3.94	43.78	37.42
19	Rohini Sector – 11	562	0.72	44.65	19.78

20	Singhola	3440	6.50	56.84	52.27
21	Asola	594	1.52	62.42	34.33
22	Hauz Khas	4920	4.37	38.35	34.65
23	Daulatpur	3780	2.06	25.49	21.62
24	Dwarka Sec-16	2020	10.10	90.55	76.19
25	PUSA	1640	3.58	57.54	45.57
26	Tagore Garden	11500	15.68	64.06	62.20
27	Janakpuri	13800	12.66	53.58	52.34
28	Peera Garhi	8840	12.04	59.84	57.53

Table A3.2: Groundwater quality parameters for Irrigation purpose in year 2015

S.No	Locations	Salinity Hazard (EC) (µS/cm)	SAR	PI	Na %
1	Akshardham Temple	1228	3.35	42.17	38.56
2	Chilla Regulator	589	0.9	26.64	25.59
3	Nizamuddin Bridge-2	891	4.04	79.35	60.89
4	India gate	5107	8.55	58.55	57.38
5	Lodhi Garden	2095	3.47	46.26	39.89
6	Safdarjung tomb	2211	4.47	54.05	47.74
7	Burarai	529.4	0.98	40.71	29.41
8	ISBT (Kashmiri Gate)	2390	1.87	34.94	24.18
9	Majanu Ka Tila	1786	5.32	80.59	67.4
10	Ushmanpur	1211	1.59	46.21	36.88
11	Wazirabad	1053	2.75	65.96	45.99
12	Auchandi	2296	3.85	52.16	43.79
13	Bakoli	3971	7.58	56.28	53.21
14	Balswa Lake	6686	10.44	60.85	58.52
15	Barwala	7208	5.38	36.26	34.99
16	Bawana	1677	3.57	57.2	46.83
17	Delhi College of Engineering	1145	3.05	63.54	46.78
18	Hareoli	2435	3.99	46.13	40.8
19	Rohini Sector – 11	2020	6.54	69.77	63.16
20	Singhola	4590	12.71	69.51	68.38

21	Asola	793	3.23	73.45	53.54
22	Hauz Khas	2785	4.68	50.31	45.46
23	Daulatpur	5068	9.11	62.03	58.11
24	Dwarka Sec-16	1564	9.21	90.9	75.49
25	PUSA	2099	5.21	64.73	52.81
26	Tagore Garden	14470	26.08	77.27	75.98
27	Janakpuri	13660	19.65	69.77	68.31
28	Peera Garhi	1070	1.21	34.91	24

Appendix 4

Table A4: Water Quality Index (drinking purpose) of groundwater

S.No	Locations	WQI for year 2010	WQI for year 2015
1	Akshardham Temple	85.26	144.79
2	Chilla Regulator	45.24	46.71
3	Nizamuddin Bridge-2	122.89	68.53
4	India gate	353.76	399.73
5	Lodhi Garden	138.02	145.79
6	Safdarjung tomb	127.47	133.23
7	Burarai	74.464	45.71
8	ISBT (Kashmiri Gate)	97.44	202.7
9	Majanu Ka Tila	139.79	150.01
10	Ushmanpur	73.15	99.85
11	Wazirabad	71.53	76.56
12	Auchandi	269.61	158.99
13	Bakoli	150.45	238.18
14	Balswa Lake	315.91	303.87
15	Barwala	259.24	432.07
16	Bawana	217.55	123.48
17	Delhi College of Engineering	95.96	124.19
18	Hareoli	316.04	183.14

19	Rohini Sector – 11	93.39	147.73
20	Singhola	255.29	247.08
21	Asola	58.02	61.9
22	Hauz Khas	239.67	368.98
23	Daulatpur	295.76	302.45
24	Dwarka Sec-16	151.99	105.17
25	PUSA	111.32	132.86
26	Tagore Garden	563.32	578.39
27	Janakpuri	674.43	557.03
28	Peera Garhi Pz	539.54	116.08

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