A Study of Groundwater Quality and Health Risk Assessment of Groundwater in Ponda City.

A Dissertation for

GEO-651: Dissertation

Credits - 16

Submitted in partial fulfilment of

Master Of Science in Applied Geology

By

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May 2024

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation report entitled, "**A Study of Groundwater Quality and Health Risk Assessment of Groundwater in Ponda City**" is based on the results of investigations carried out by me in the Master of Science in Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa university under the Supervision of Assistant Professor Mr. Mahesh Mayekar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations or other findings given the dissertation.

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COMPLETION CERTIFICATE

This is to certify that the dissertation report "**A Study of Groundwater Quality and Health Risk Assessment of Groundwater in Ponda City**" is a bonafide work carried out by Ms. Simran Pundalik Gaonkar under my supervision in partial fulfilment of the requirements for the award of the degree of Master of Science in the Discipline Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University.

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PREFACE

Groundwater, as a vital natural resource, plays a crucial role in sustaining ecosystems and meeting the water needs of communities worldwide. However, ensuring its quality and safety for consumption is imperative, especially in urban areas where population density and industrial activities can significantly impact groundwater quality.

This research work delves into the assessment of groundwater quality and heavy metal contamination in Ponda city, shedding light on the intricate interplay between environmental factors and human activities. Through meticulous sampling and rigorous analysis, this study aims to provide insights into the current state of groundwater in the area, particularly focusing on post-monsoon conditions.

The methodology employed encompasses a comprehensive assessment, including the measurement of key parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), and the determination of major cations like calcium, magnesium, sodium, and potassium. Furthermore, heavy metal concentrations, including iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn), were evaluated using advanced analytical techniques, with comparisons made against established standards for drinking water quality.

In addition to individual metal concentrations, this study utilizes established indices such as the Heavy Metal Pollution Index and Metal Index to provide a holistic assessment of heavy metal contamination levels in the groundwater of Ponda city. Moreover, the determination of total hardness through EDTA titrimetric method offers valuable insights into the overall water quality and its suitability for various domestic and industrial purposes.

By synthesizing these findings, this research contributes to the broader understanding of groundwater quality dynamics and aids in informed decision-making for sustainable water resource management and public health protection. It is hoped that the outcomes of this study will serve as a foundation for future research endeavours and policy interventions aimed at safeguarding the precious resource of groundwater for generations to come.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who have helped me in the completion of my Dissertation.

Firstly, I would like to thank my Guide Mr. Mahesh Mayekar, Assistant Professor, School of Earth Ocean and Atmospheric Sciences for his guidance, patience and support throughout my research journey. I appreciate his valuable insights, constructive feedback, and encouragement, which have played a pivotal role in shaping my ideas and strengthening my arguments.

I am especially thankful to my parents for their constant support during my entire dissertation. Also, I am thankful to my best friend Mr. Presit Parsekar and my brother Mr Venkatesh Gaonkar for their help, support and encouragement.

A special thanks to my friend Mr. Aaron Pereira, who helped me a lot during my dissertation. His contributions have been very useful for completion of my research.

I would like to thank Mr. Rajesh, lab assistant for his help. Further I would like to acknowledge my friends and all those who stood by my side during this entire dissertation in some way or the other.

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ABBREVATIONS USED

Entity	**Abbreviation**
Bureau of Indian Standards	BIS
Electrical conductivity	EC
Heavy metal pollution index	HPI
Metal index	MI
Total dissolved solids	TDS
United States Geological Survey	USGS
Water quality index	WQI
World Health Organisation	WHO

ABSTRACT

The study focuses on the Groundwater quality and heavy metal assessment of groundwater in Ponda city. 15 representative groundwater samples were collected from well during post monsoon in the month of December 2023 from household wells. Various parameters like pH, EC and TDS were measured. The major cations Calcium, magnesium, sodium and potassium was found out. The Total Hardness was also measured by using EDTA titrimetric method. Heavy metals like Iron (Fe), Manganese (Mn), Copper (Cu) and Zinc (Zn) were found out by using AAS spectroscopy and compared with BIS 2012 for drinking appropriateness. The Water Quality Index was calculated using 8 parameters which are pH, EC, TDS, Sodium, Potassium, Calcium, Magnesium and Total Hardness for 15 samples. Heavy metal assessment was done by pollution Evaluation indices such as Heavy Metal Pollution Index (HPI) and Metal Index (MI) by assessment of 11 well water samples. The study will help in groundwater assessment for suitability of drinking water and determining groundwater flow in Ponda city.

CHAPTER 1: INTRODUCTION

1.1 GENERAL

Water plays a vital role in our lives. Water covers 75% of earth surface, the water present on the earth's surface is mostly the oceanic waters i.e. 97% which is not suitable for humans to use, 2% is present as ice and only 1% can be used for human consumption as it is fresh water like lake, streams, and rivers (Gurdeep Singh and Rakesh Kant Kamal., 2014). India uses 230 km^3 groundwater every year. Over 80% of India's population gets water supply from the ground as stated by ministry of Jal Shakti.

Groundwater is never pure, there will be some contamination present depending on what is the source of water, soil conditions, residence time of pollutants, groundwater flow etc. It will also change with anthropogenic involvement like disposal of sewage, agricultural activities and release of chemicals from industries etc contributing to disruption in groundwater quality. (Ministry of Jal shakti, 2023).

Groundwater many times have trace amounts of heavy metal which impacts human health adversely. It brings toxicity and high exposure can lead to various health related risk, so limits are set by BIS for drinking water (V.C Goyal et al., 2022). Heavy metal enters the groundwater by various anthropogenic activities including mining, metal smelting, industrial manufacturing, municipal sewage, medical residues, fertilizer overuse, untreated industrial waste, Solid waste dumping sites, Acid mine drainage etc (Vasant Wagh et al, 2018). There are complications in behaviour of heavy metals in aquifer, which is associated with the lithology, water source and biogeochemical processes (Anjali Nayak et al.,2023). Studies showed that industrialization and urbanization causes threatening heavy metal pollution from industrialized age.

Due to industrialization and urbanization, there is excess use of fertilizers, pesticides and waste discharge, this leads to release of heavy metal in the soil which eventually entered the groundwater (Young Liu et al, 2014) solubility of heavy metals depends on their pH, at low pH the solubility tends to be high. All living organisms need trace amounts of heavy metals in their body i.e. Iron, cobalt, copper, manganese, molybdenum, and zinc are essential for humans. But these heavy metals at higher concentration may prove toxic to our bodies and produce damage to living organisms and accumulation of such metals can cause serious illness. (Reena Singh., 2011). Humans can come in contact with heavy metal via three ways, inhalation, oral ingestion and skin contact through exposure of contaminated water and air (Vasant Wagh et al., 2018). Increase in quantities of heavy metal in groundwater makes the water unsafe for drinking. Heavy metal particles tend to be reactive mobile and highly toxic, so their fate in environment is of great concern. Heavy metal contamination poses threat to living organisms including humans and is the main cause of severe health issues (Simona Pintilie., 2007). Agricultural activities also contribute to the contamination of soil and water by heavy minerals. Heavy metals if increased above the safe limit poses health implications which may result in physiological or morphological abnormalities or genetic mutations.

So, monitoring of heavy metals is important, this can be done by WQI (Water quality index) which provides a single number that expresses the overall water quality, at a certain location and time, using water quality parameters (Ruth Olubukola Ajoke Adelagun, 2021). Water quality can also be determined by Pollution Evaluation indices, the indices for heavy metal contamination are HPI and Metal Index which gives overall account of groundwater quality. The HPI and metal index calculated by using ratio of measured values of heavy metals and their BIS standard Permissible limit (Vasant Wagh et al., 2018).

1.2 PHYSIOGRAPHY

Goa lies on the west coast of India between latitudes 14°53′54″ N and 15°40′00″ N and longitudes 73°40′33″ E and 74°20′13″ E. Goa covers an area of 3,702 km^2. The state can be divided into three terrain, coastal estuarine plain, undulating regions in the centre and the western Ghats. (Fig. 1.1).

1] western coastal estuarine plains -- The coastal plain in south Goa is small and mostly it is hilly region even on the coast whereas in North Goa the coastal plain is broad and salient. It extends 10-12 km inwards from the shoreline. The features seen are Khazan lands, settlement places, sandy beaches, saltpans, estuarine swampy areas and mangroves.

2] Central hilly region

This region has relict hills having elevation varying from 100 to 600 meters. This region lies between the coastal Estuarine plains and the western Ghats. The midland hilly region is wider in the North as compared to the south, because the western ghats in the north is situated far inland in the North. The hills in this region are parallel to the coast.

3] The western Ghats

The western ghats are also called the Sahyadri. This region consists of hills with steep slopes and higher elevation ranging from 600 to 1000 meters high. The western ghats in the north Goa are trending in NW-SE, and in the South Goa is the WNW-ESE trend. The South Goa (Taluka – Quepem and Canacona) have very little region of coastal estuarine plain which changes abruptly from midlands to western ghats. (O.A. Fernandes, 2009).

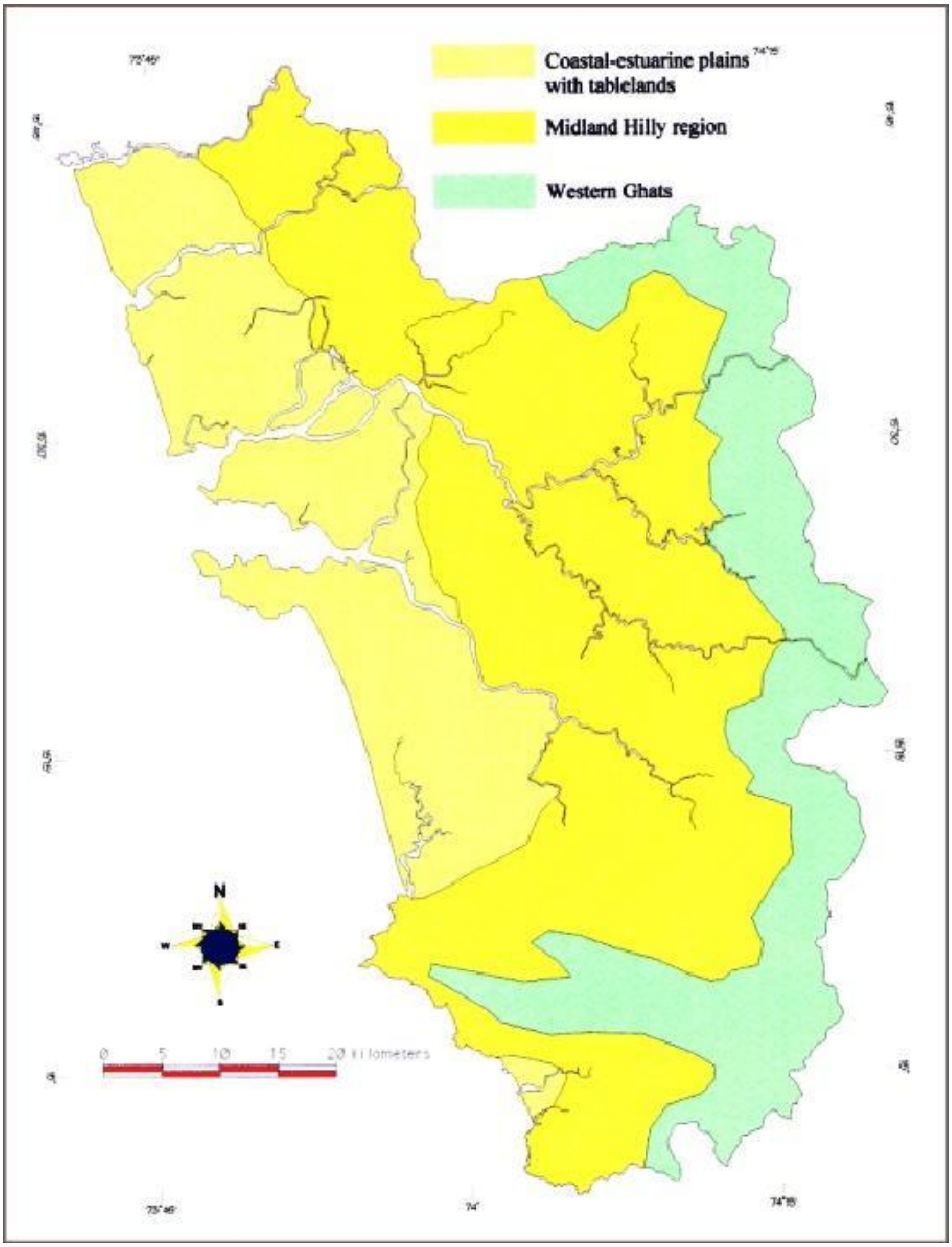

Figure 1.1 – Map showing Physiographic divisions of Goa. (Source: O.A. Fernandes, 2009).

1.3 DRAINAGE

There are 9 rivers that cover the Goa state, Terekhol, Chapora, Baga, Mandovi, Zuari, Sal, Saleri, Talpona and Galgibag. On the west, Goa is surrounded by Arabian sea that stretches for 105km long in the state. (A. G. Chachadi, 2009). This water is not only a source of potable water, but also used for agriculture, transportation of goods and for domestic purpose. The river flows from western ghat, travel through midland and then enters the Arabian sea through the coastal plains. From these 9 rivers, River Chapora and Terekhol is shared by 2 states, originating from Maharashtra and continue flowing in Goa, whereas river Mandovi originates from Karnataka and flows in Goa. Rest of the Rivers are restricted within the Goa state boundary. (SANDRP, 2016).

Table 1.1 – Surface Runoff and Catchment Area of Major Rivers in Goa. (Source – A. G. Chachadi, 2009)

S. No.	River Basin	Catchment area (km^3)	Surface run-off (MCM)
01	Terekhol	71	0164.25
02	Chapora	255	0588.35
03	Baga	50	0116.42
04	Mandovi	1550	3580.04
05	Zuari	973	2247.40
06	Sal	301	0694.39
07	Saleri	149	0343.04
08	Talpona	223	0515.59
09	Galgibag	81	0187.11
			Total 8436.59

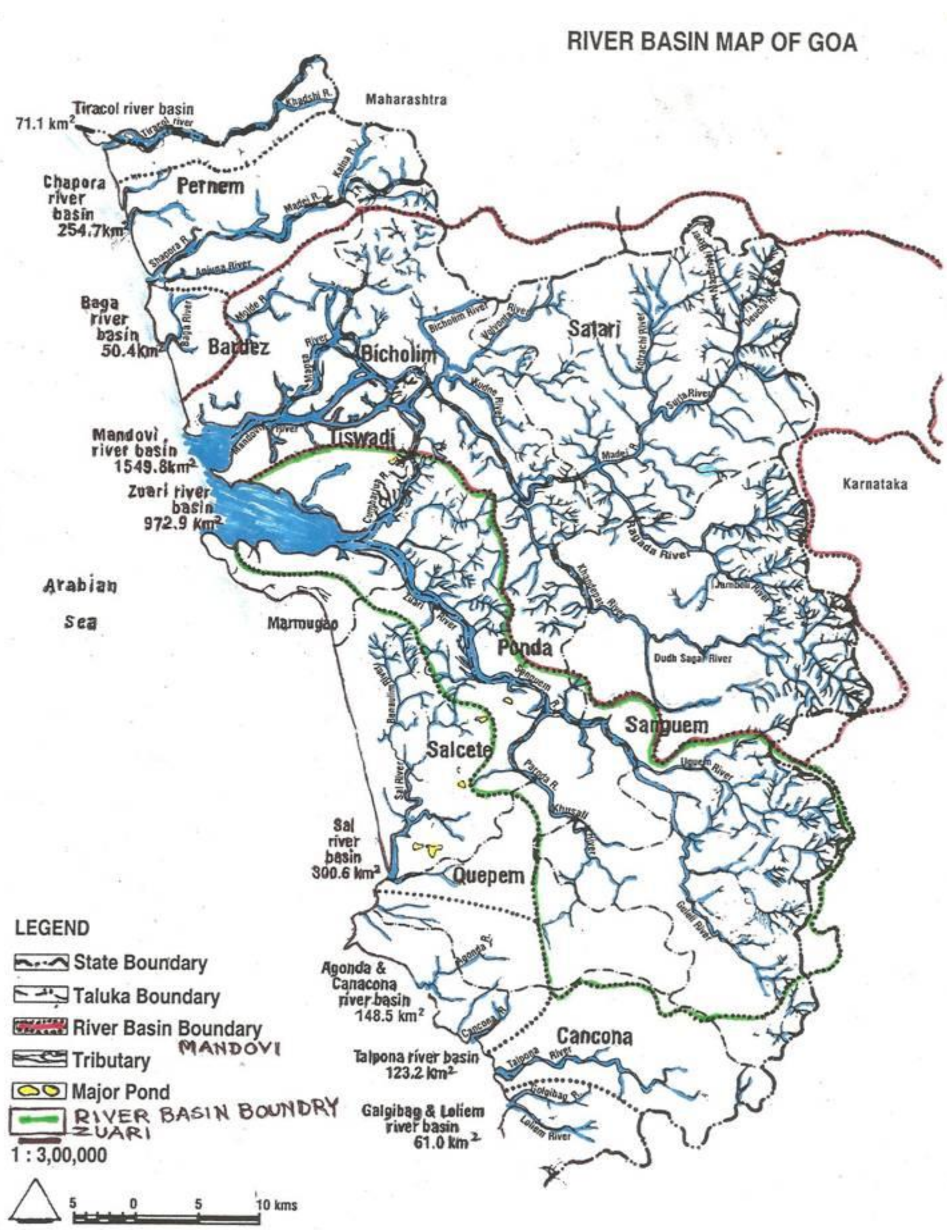

Figure 1.2 – River Basin Map of Goa. (Source: Goa State Remote Sensing Centre)

1.4 GEOLOGY OF GOA

The classification proposed by Gokul et al (1985), Goa is divided into 4 formations, Barcem formation, Sanvordem formation, Bicholim formation and the Vagheri Formation. Later A.G. Dessai revised the classification into 2 major Groups, Barcem Group and the Ponda Group. An unconformity separates the two groups. Ponda Group was further divided into three formations – Sanvordem Formation, Bicholim Formation and the Vagheri Formation.

Anmode Ghat Trondhjemite Gneiss: The age of these rocks is 3300-3400 Ma. It is a basement rock found exposed on Anmode, along the Panjim – Belgaum national highway. Trondhjemite-tonalite gneisses (TTG suite) are also seen in South Goa at Chauri, Palolem and Agonda along a WNW-ESE trend. Quartzofelspathic augens and K-feldspar (microcline) are also seen.

Chandranath Granite Gneiss: The age of these rocks is 2700-2900 Ma. The exposure of rocks is seen at Paroda and Quepem extends from Sanguem to the Colva-Banaulim (Gokul et al 1976). It composes of grey granitic gneiss which ranges from granodiorite to quartz-diorite.

Barcem Group: Barcem group is exposed at the southeast of Barcem village. The base of Barcem group consist of quartz-pebble conglomerate, the other lithology consists of metavolcanics with intercalations of quartzites and pelites. Metasediments found are quartzites, quartz-sericite-schists, quartz-chlorite-schists and minor phyllites. Volcanic rocks present are lava, agglomerate and tuff. In the central Goa around regions including Astagal, Polem, Padi and Subdalem in the south and Tisk (Usgao)-Dharbandora, the rocks like Non vesicular Metabasalts are exposed. Gulem and along saleri – Vagon road, vesicular basalts are found.

Ponda Group: It Comprises of three formations; Bicholim Formation, Vagheri formation and Sanvordem formation.

Sanvordem formation: The base for Sanvordem formation is Chandranath granite gneiss, consist of metagreywacke and argillite, and polymict Metaconglomerate is present at the base. Conglomerate comprises of lengthened pebbles of gneiss and quartzite in a schistose chlorite matrix. Along River Mandovi between Baga and Aguada, there is exposure of laminated Argillites. Metagreywacke displays graded bedding.

Bicholim Formation: The formation extends from Naibag in the northwest to Salgini in the southeast trending in NW-SE, and it is 1.4 km wide in thickness (Gokul et al. 1985). The rocks found are, Ferruginous, amphibole schists limestones, banded ferruginous quartzites (BHQ) Intercalated with phyllite and manganiferous phyllites. The banded iron Formation (BIF) of haematite and magnetite sub facies are exposed in this region. The most common lithology in this formation is quartz-chlorite-Tremolite schists and ferruginous phyllites.

Vagheri Formation: It lies above the Bicholim formation. The rocks exposed in Vagheri formation are metagreywacke-argillite with Intercalation of metabasalts. The exposure is best seen in NE of Valpoi. There is presence of tapered metabasalts. Its colour is greenish grey consisting of indistinct schistosity. It comprises of tremolite/actinolite, zoisite, chlorite, epidote, plagioclase, and may be opaque quartz (A.G. Dessai., 2011).

Table 1.2: Lithostratigraphic classification of rocks from Goa (Source: A. G. Dessai., 2011)

Basic Intrusives		Metadolerite/Dolerite
Canacona Granite	2395±390 (?) Ma	Porphyritic potassic granite
Mafic-ultramafic layered complex	Peridotite-Gabbro	Dunite-peridotite-gabbro complex and equivalents
Ponda Group (≡ Chitradurga Group)	Vagheri Formation	Metabasalt Argillite and metagreywacke
	Bicholim Formation	Banded ferruginous quartzite Manganeferous chert breccia with pink ferruginousphyllite Limestone Pink ferruginous phyllite Quartz-chlorite-amphibolite-schist
	Sanvordem Formation	Metagreywacke Argillite,quartzite,tilloid
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ Unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		
Barcem Group (≡ Bababudan Group)	Barcem Formation	Matagabbro Peridotite, talc-chlorite schist Quartzite, quartz-sericite-schist Red Phyllite Quartz porphyry Massive, schistose and vesicular metabasalt
~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ Unconformity ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~		
Chandranath Granite Gneiss	2700-2900 Ma	Granodiorite
Anmode Ghat trondhjemite gneiss	3300-3400 Ma	Basement: trondhjemite-tonalite-granodiorite

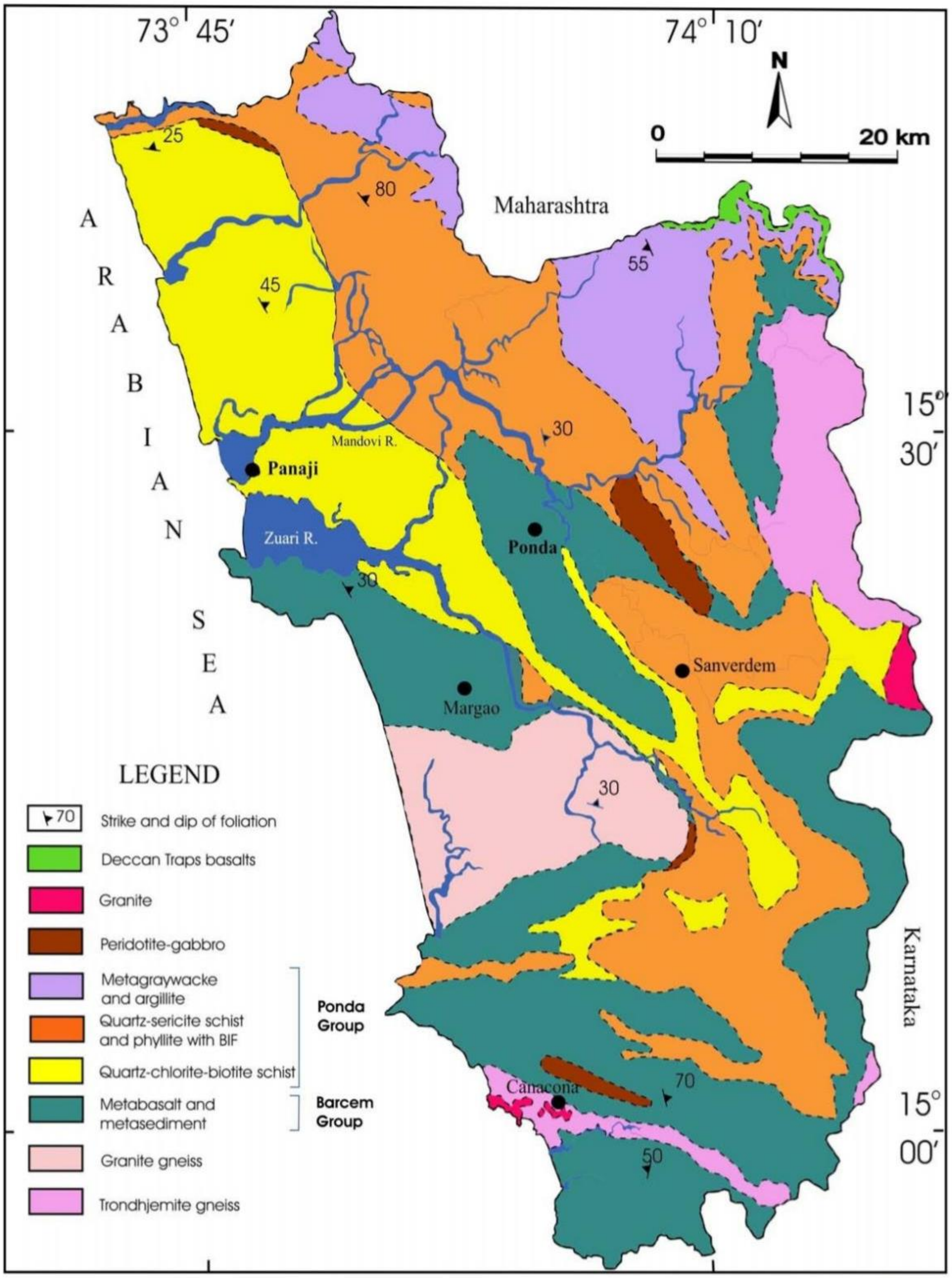

Figure 1.3: Geological map of Goa (Source: A.G. Dessai., 2011)

1.5 CLIMATE IN GOA

The hilly terrain plays a vital role in rainfall patterns in Goa. Movement of monsoon circulation varies with orology. Valpoi receives the maximum rainfall, it is because of the orology. (S. M. Metri and Khushvir Singh., 2010). Goa is surrounded by Arabian Sea in the West, and it falls in the tropical zone, so it is having Hot and Humid weather conditions for maximum period of the year. The highest temperature is seen in the month of May, when the temperature rises to ~ 35°C during the day time along with high humidity, whereas the temperature falls up to ~20°C at night and ~29°C during day in winters during the months of December to February. (Department of Information & Publicity., 2024). The mean annual rainfall over the 29 years is 330 Cm (S. M. Metri and Khushvir Singh., 2010).

1.6 STUDY AREA

1.6.1 Location

The study area is situated at the central portion of the state Goa, in the Ponda Taluka of North Goa district. The study area comprises of Ponda city covering an area of 5.22 Sq. km. The study area is covered in the Survey of India toposheet 48E15-NE-B3 and 4813-NW-B1 of scale 1:50,000. Population in Ponda is approximately 22,664 (2011 census). Ponda city is surrounded by villages like Curti, Quela, Bethora and Bandora. Ponda city is an urban area having high population density. The figure 1.4 shows the location of study area.

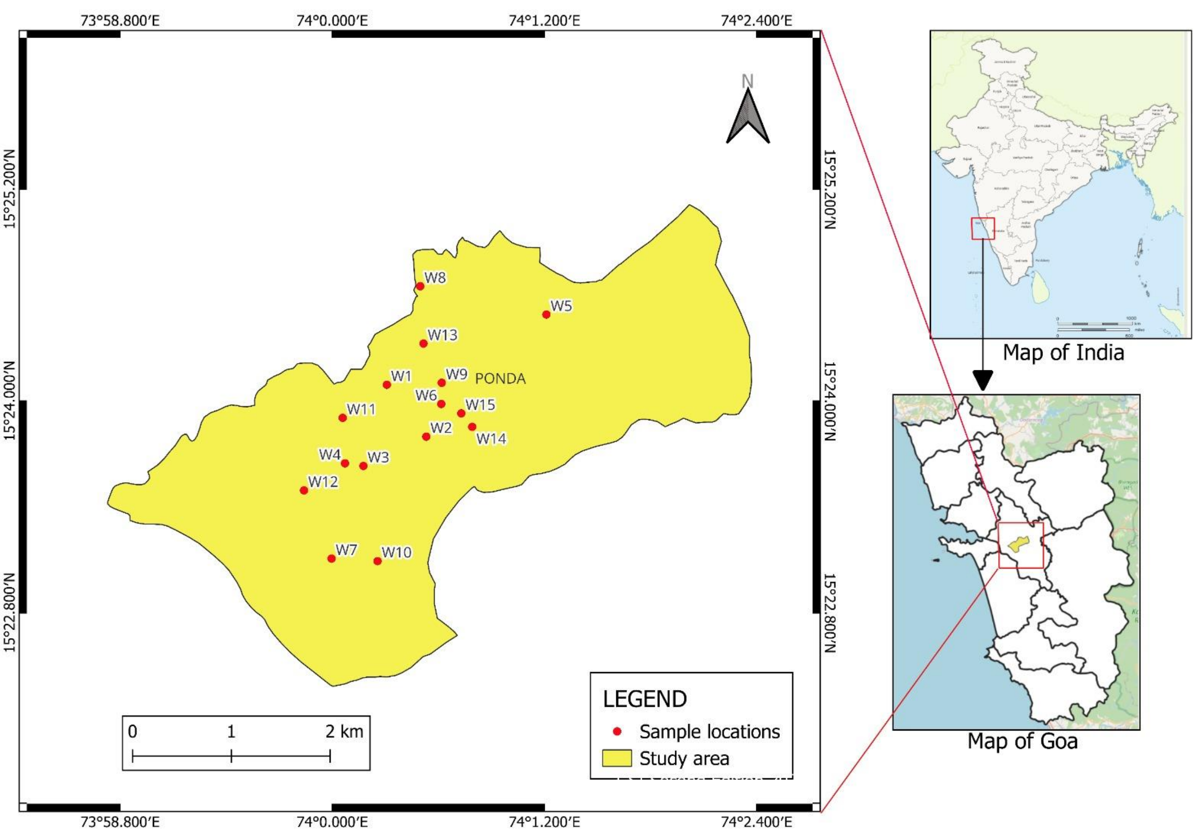

Figure 1.4: Location Map of Study Area

1.6.2 Hydrology of study area

The residents of Ponda city use water for variety of purposes which includes drinking, domestic use, agricultural and industrial purposes. Hence hydrology is very crucial. The groundwater flows from South East to North Western region in the study area and finally empties into river Zuari. The drainage map is shown in the fig 1.5.

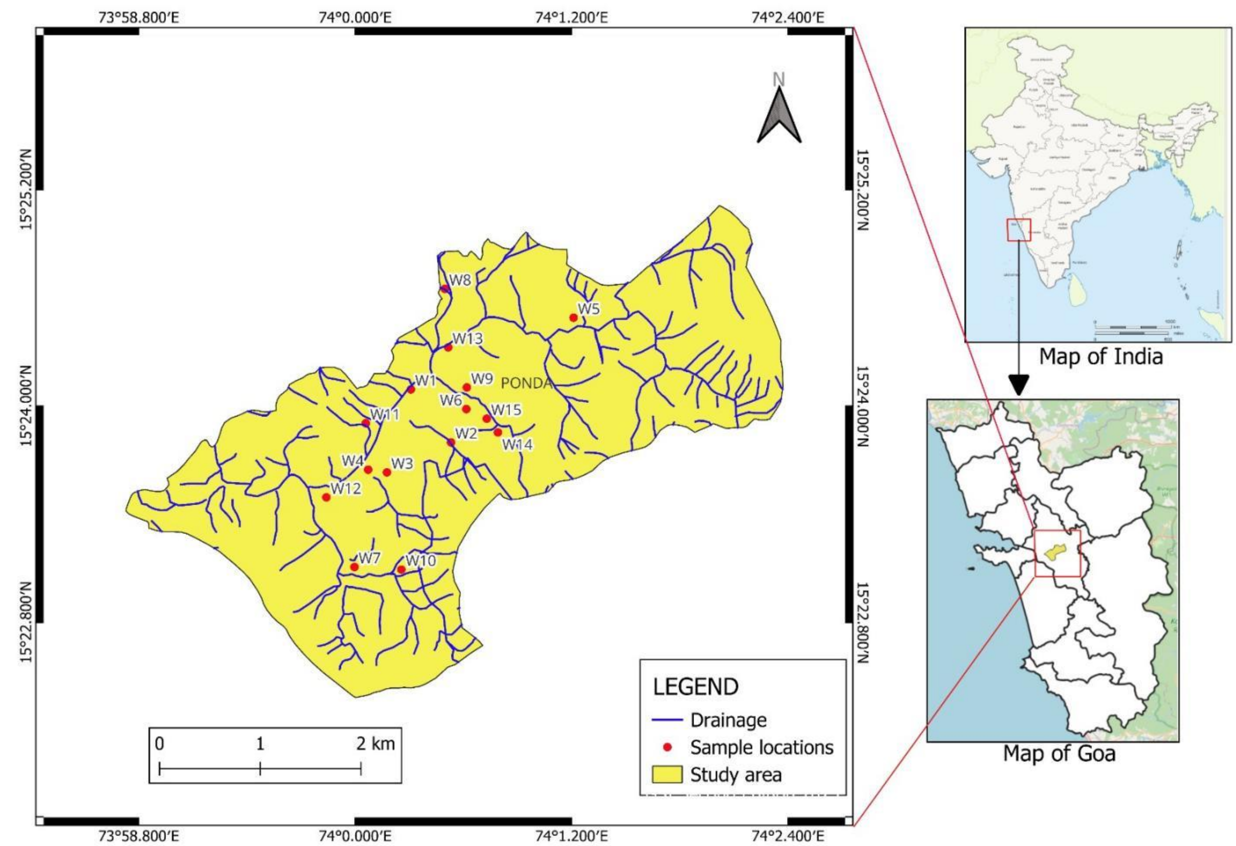

Figure 1.5: Drainage map of study area

1.6.3 Topography of study area

Topographically, the Ponda city is present in the Midland hilly region according to the physiographic division of Goa (O.A. Fernandes., 2009). Ponda is having an elevation of 5 to 208 metres above msl. North eastern region and the South western region is having higher elevation. The central region has lower elevation and the majority of wells are found in this region. The topographic contour map is displayed in fig 1.6.

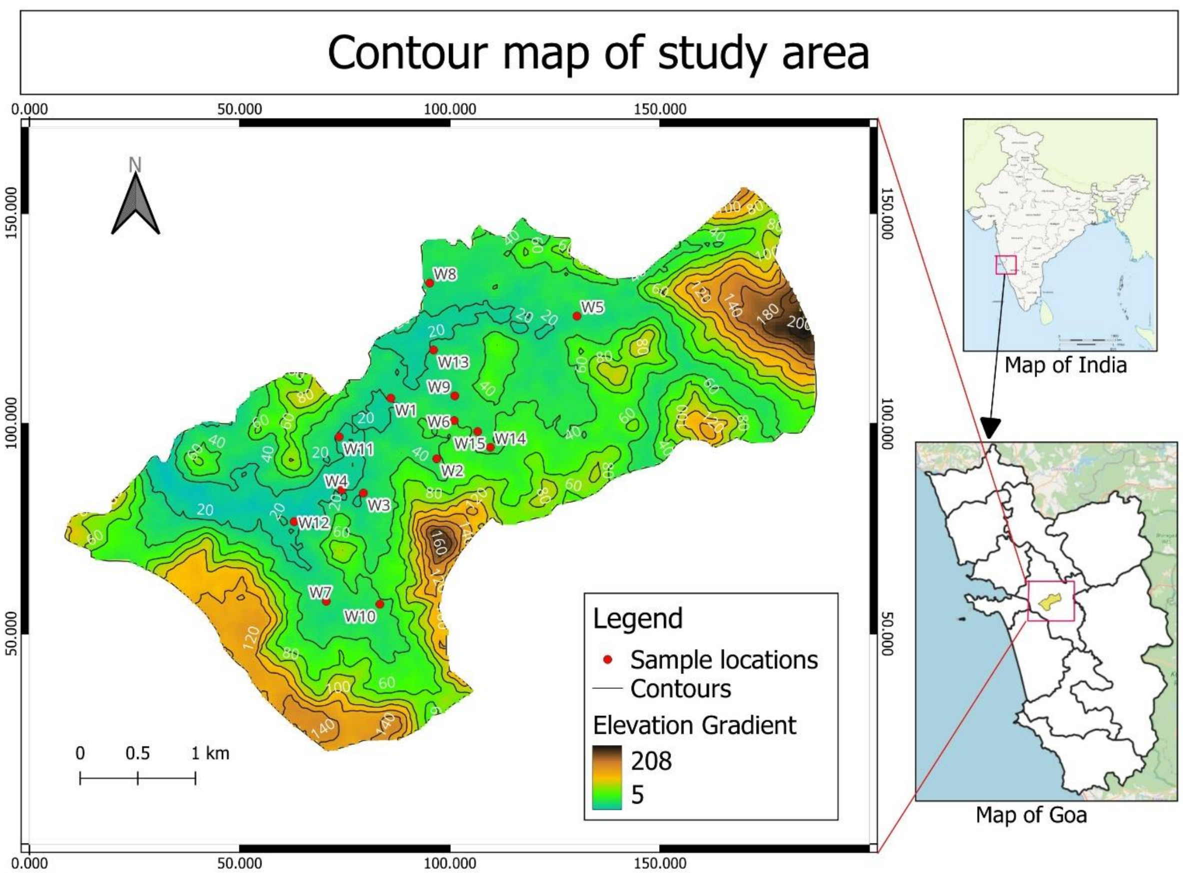

Figure 1.6: Topographic Contour Map of Study Area

1.6.4 Geology of study area

The study area has lateritic exposure. Ponda city consist of Chlorite schist of Bicholim formation and Argillite of Sanvordem formation. There is small patch of clayey sand in the study area. There is also presence of dolerite intrusive. The geological map of the study area is illustrated in Figure 1.7.

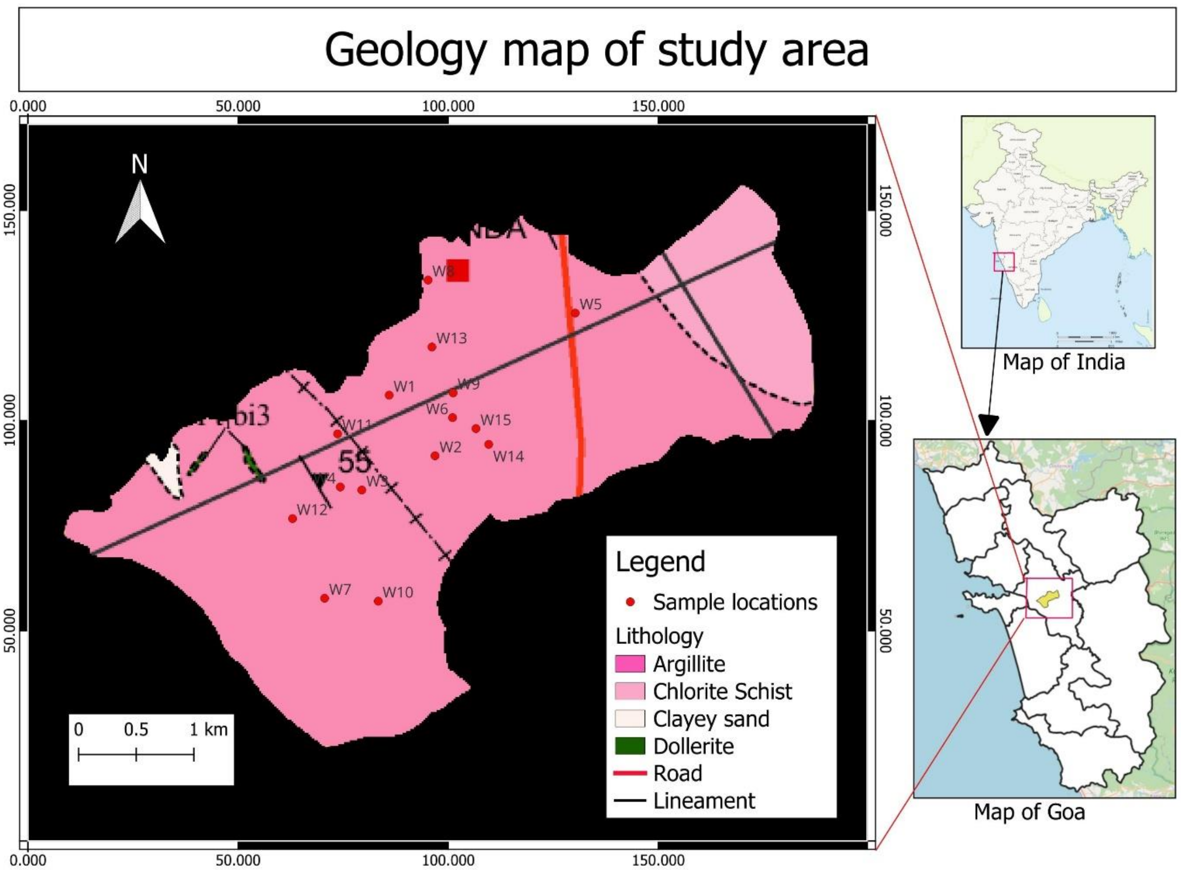

Figure 1.7: Geological map of study area (Source: GSI)

1.6.5 land use and land cover

The maximum area is residential area which is 59% of the total area in Ponda, followed by commercial area which accounts for 10%. There are also natural resources covering 8% of Ponda city where it includes forest and rangeland. Various semi government and public areas are also seen, along with recreational areas. Agricultural land is covering 10.44 hectares. (Sewerage and infrastructure development corporation of Goa Ltd., 2014). The land use map of study area is shown in figure 1.8.

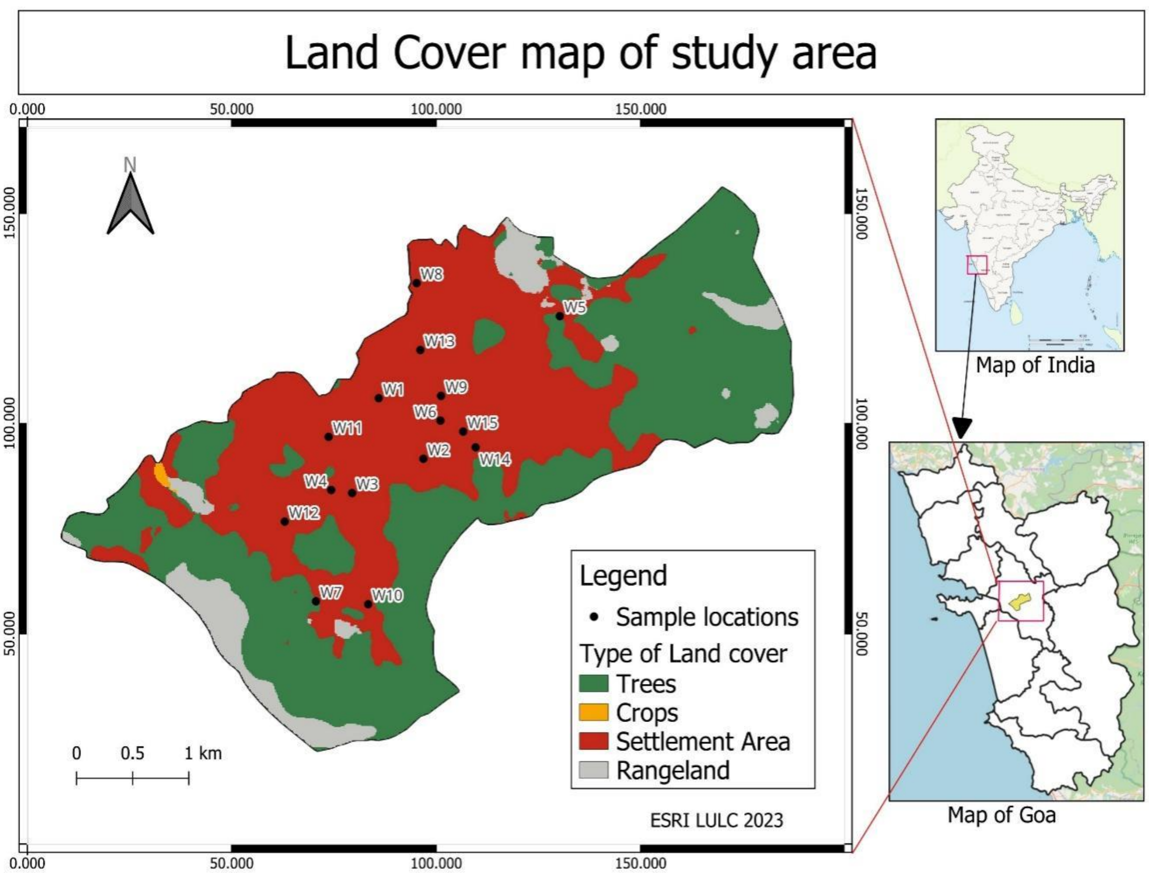

Figure 1.8: Land Cover Map of Study Area (Source: ESRI., 2023)

Table 1.3: land use in Ponda city (Source: Sewerage and infrastructure development corporation of Goa Ltd, 2014).

No	Land Use	Area in hectares	Percentage of Total
1	Residential	307.76	59.00%
2	Commercial	52.2	10.00%
3	Industrial	2.61	0.50%
4	Public/Semi Public	20.88	4.00%
5	Roads	26.1	5.00%
6	Recreational	10.44	2.00%
7	Natural Resources	41.76	8.00%
8	Open space	15.66	3.00%
9	Defense Land	5.22	1.00%
10	Water body	18.27	3.50%
11	Settlement	5.44	1.00%
12	Parking	5.22	1.00%
13	Agricultural	10.44	2.00%

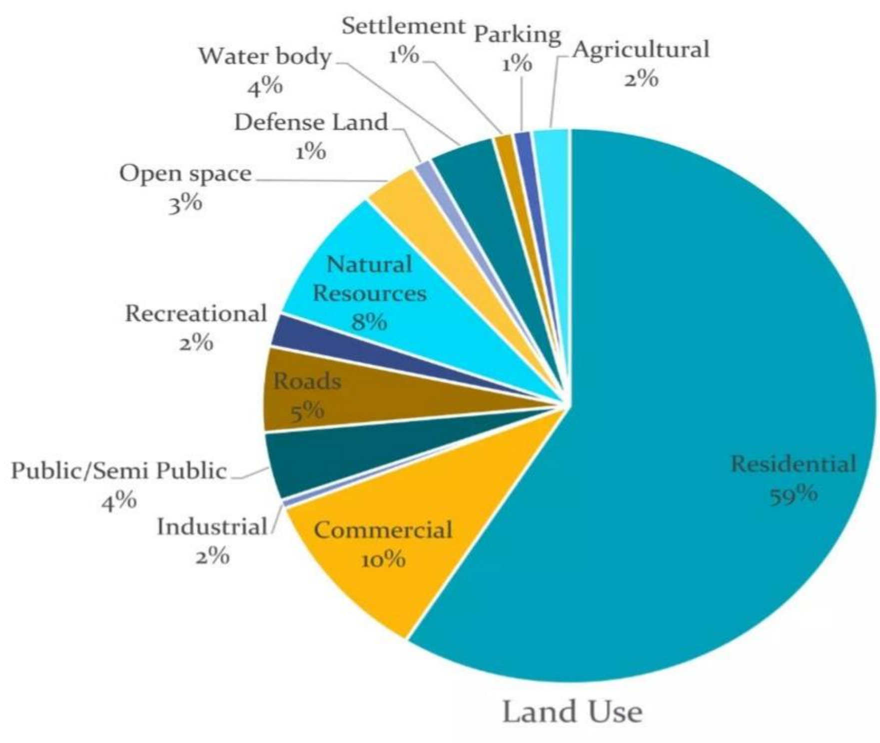

Figure 1.9: land use percentage (Source: Sewerage and infrastructure development corporation of Goa Ltd., 2014).

1.6.6 Soils

The soil present in the study area is lateritic. The lateritic soil consists of large amounts of iron and aluminium giving it an orange to red colour. The soil in Ponda along slopes are highly prone to Sliding. There is also presence of clay content, sand and gravel. The soil is good for cashew nut crops.

1.6.7 Climate and Rainfall

The climate in the study area is tropical. There is a prominent rainfall seen in majority of the months in a year. The average temperature is 26.2°C / 72.9°F. The annual rainfall in Ponda city is 3124 mm / 123.0 inch. Due to the presence of equator at close vicinity, defining summers is difficult. July month has the highest humidity and February being the driest month of the year. (Climate data. Org)

1.6.8 Population Density of Study Area

The population of North Goa in 2022 according to Aadhar card estimates is 853,591. According to census 2011, The population of North Goa was 818,008. Ponda city has 13 wards with 2517 households. The population in Ponda city was 12722, among which males were 7263 and females were 5459. The Childrens between the age of 0-6 years was 1098. Ponda city has a good literacy rate of 81.82, from which literate males are around 87.06% and literate females are around 74.85%.

1.7 OBJECTIVES OF THE STUDY

The study aims to assess the groundwater quality and groundwater flow and also infer about health risk assessment using heavy metal contamination.

The main objectives of the study are:

1. To study groundwater flow net using groundwater level.
2. To study the groundwater quality and its suitability for drinking purpose by analysing major cations.
3. Heavy metal assessment in groundwater and study Pollution Evaluation indices such as Heavy Metal Pollution Index (HPI) and Metal Index (MI).
4. To study overall quality of water by using the Water Quality Index (WQI).

CHAPTER 2: LITERATURE REVIEW

A study was carried out in mining regions of Goa for groundwater quality and heavy metal assessment in the year 2016 by Gurdeep Singh and Rakesh Kant Kamal. The heavy metal concentrations were analysed by atomic absorption spectrophotometer for zinc, chromium, copper, cadmium, manganese, iron and lead. All were within the permissible limit except for Fe content which is above the permissible limit according to BIS guidelines. The Heavy metal Pollution Index (HPI) was less than 100, which indicates the wells were not polluted having low to medium HPI.

Hydrogeological assessment was done by Ibrampurkar and Chachadi (2012) in Mhadei river Watershed, groundwater level from ground was measured and then groundwater level above msl was determined by using elevation data from google for making groundwater flow net. Water level changes were observed in both the seasons. Using groundwater flow net, the direction of groundwater flow was determined.

Health risk assessment was done by Vasant Wagh (2018) for heavy metal contamination in Kadava river basin, Nashik. Extreme levels of chromium, lead, cadmium, nickel and iron was seen in groundwater, this was due to the anthropogenic activities like agriculture. The heavy metal pollution index (HPI) of groundwater was more than the critical limit hence the water was unfit for drinking. The heavy metal evaluation index (HEI), Majority of the samples (82.5%) were having high pollution range and few samples (17.5%) were having medium pollution range.

Elumalai Vetrimurugan et al., in the year 2016 carried out study of groundwater quality determination and human risk to heavy metal exposure. Six locations had extreme Electrical conductivity of more than 3000 (µS/cm) which makes the water unsuitable for drinking. Elevated levels of aluminium, silver, copper, lead, iron, boron, manganese, nickel, cadmium was observed which is unfit for consumption. The HPI in groundwater samples was varying from 47 to 104. Majority of the study area had poor water quality.

The heavy metal pollution index (HPI) and the metal index (MI), two of the most recent heavy metal indices, were used in this study to assess the quality of Sirwan River water based on its heavy metal contents. 24 sampling stations were chosen for this term, spaced along the Sirwan River from the Darbandikhan Dam downstream to the Jalawlaa Sub-district border. Using an inductively coupled plasma spectrometer (ICP), seven heavy metals were examined: aluminium (Al), iron (Fe), zinc (Zn), cadmium (Cd), lead (Pb), nickel (Ni), and chromium (Cr). For drinking and irrigation purposes, respectively, the average HPI index value was determined to be 47.2 and 12.8. This suggests that the water in the Sirwan River is substantially contaminated for drinking purposes, but it is classified as pure for irrigation purposes. Furthermore, it was observed that the MI findings for irrigation and household usage were 0.65 for the pure class and 5.7 for the significantly affected class. The study demonstrated how human-caused pollution affects the water quality of the Sirwan River (Abdulmutalib Raafat Sarhat and Basim Shakir Al-Obaidi., 2022).

Physico-chemical data exhibit notable variability across all sixteen sampling locations within the research area (District Varanasi). In the lab, water samples have been examined for seven physico-chemical parameters, including pH, calcium, magnesium, chloride, sulfate, nitrate, and electrical conductivity, in accordance with Bureau of Indian Standards (BIS) standard operating procedures. The drinking water quality standards specified by the World Health Organization (WHO, 2004), the Bureau of Indian Standards (BIS, 1993), and the Indian Council for Medical Research (ICMR, 1975) have been used to calculate the WQI. It is discovered that, of the test stations, 55.56 percent have good quality drinking water, whereas 22.23 percent have low water quality. Merely 11.12% of the water that is used for drinking is unsafe. It is evident that over 50% of the water samples are of high quality and suitable for drinking. The total number of WQI readings for the seven stations shows that the water quality is not suitable for drinking and that usage must be preceded by prior treatment. Excellent water quality is demonstrated by the S5 and S6 stations (Araziline development block). Good water quality was reported in the majority of the research region, which includes the blocks of Bragaon, Sevapuri, and Harhua. Water quality is bad in the Chirajigan and Kashi Vidyapeeth blocks. (Rajesh Prajapati and Ram Bilas., 2018).

CHAPTER 3: METHODOLOGY

3.1 PRE FIELD-PREPARATION

Google Earth pro was used to locate the wells in Ponda City by using the survey of India toposheets 4813-NW-B1 and 48E15-NE-B3. Then a base map was created with the help of QGIS and the study area was recognised by using the city boundaries from Survey of India Map Series and Diva GIS portal. For collection of data, a format was created to note down the depth to the groundwater level, the thickness of the water column and the overall depth of the wells.

3.2 FIELD DATA COLLECTION

Monitoring drilled, tube, or dug wells is the most used technique for examining the quality of groundwater. There was a field visit to determine which wells were available. Fifteen well samples were taken from various locations inside Ponda City to assess groundwater quality, groundwater levels, and heavy metal contamination. The well location that was chosen for assessment is seen in figure 3.1. The wells that are evaluated in this study area are listed with their latitude and longitude in table 3.1. Table 3.2 displays the pre-formatted sheet containing all the collected data that is crucial for the investigation of the well site. Four days of field work was needed to gather all the field data by December 2023. Using portable tools, other parameters such as pH and EC of the groundwater for 15 wells were determined in the field.

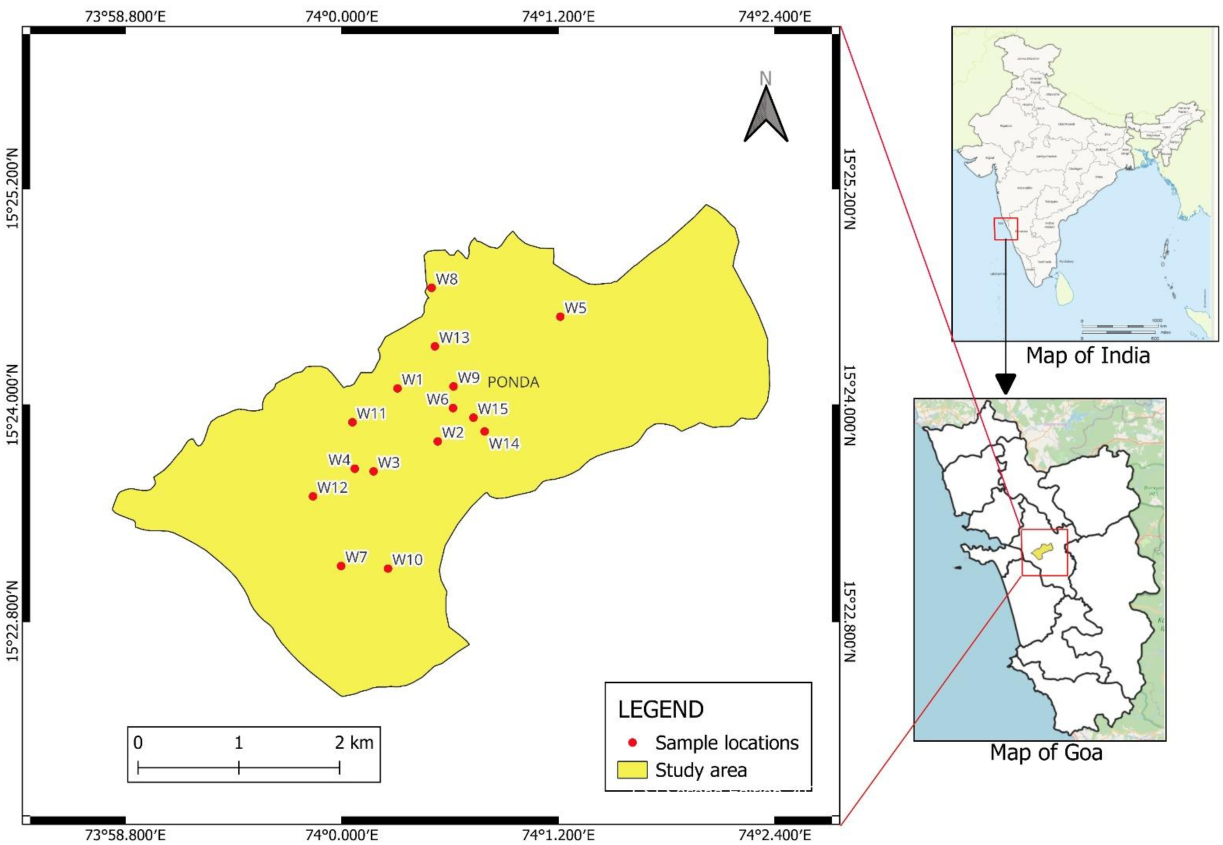

Figure 3.1: Location Map of study Area

Table 3.1: Latitude And Longitude of Wells in The Study Area

Sr. No	Well samples	Latitude (DMS)	Longitude (DMS)	Latitude (Decimal)	Longitude (Decimal)
01	W1	15°24’05.5” N	74°00’18.6 E	15.4015369	74.0051531
02	W2	15°23’47.9” N	74°00’31.9” E	15.3966295	74.0088603
03	W3	15°23’37.9” N	74°00’10.6” E	15.3938699	74.0029390
04	W4	15°23’38.8” N	74°00’4.3” E	15.3941227	74.0012063
05	W5	15°24’29.4” N	74°01’12.7” E	15.4081608	74.0201977
06	W6	15°23’59” N	74°00’37” E	15.3997220	74.0102780
07	W7	15°23’6.5” N	73°59’59.8” E	15.3851265	73.9999406
08	W8	15°24’38.4” N	74°00’26.8” E	15.4106610	74.0074320
09	W9	15°24’6.2” N	74°00’37.2” E	15.4017195	74.0103214
10	W10	15°23’5.6” N	74°00’15.4” E	15.3848873	74.0042710
11	W11	15°23’54.3” N	74°00’3.5” E	15.3984083	74.0009790
12	W12	15°23’29.6” N	73°59’50.4” E	15.3915593	73.9973422
13	W13	15°24’19.5” N	74°00’31” E	15.4054225	74.0085988
14	W14	15°23’51.2” N	74°00’47.5” E	15.3975610	74.0132078
15	W15	15°23’55.8” N	74°00’43.8” E	15.3988249	74.0121587

TABLE 3.2: Data Recording Format

01	Serial No.
02	Well No.
03	Latitude (DMS)
04	Longitude (DMS)
05	Latitude (decimal)
06	Longitude (decimal)
07	Depth to groundwater level (mts.)
08	Thickness of water column (mts.)
09	Total well depth (mts.)
10	Shape of the well
11	EC (surface)
12	pH

Table 3.3: Table Representing the Shape of Wells**.**

Sr. No	Well samples	Latitude (DMS)	Longitude (DMS)	Shape
01	W1	15°24’05.5” N	74°00’18.6 E	Semi-circle
02	W2	15°23’47.9” N	74°00’31.9” E	Circle
03	W3	15°23’37.9” N	74°00’10.6” E	Circle
04	W4	15°23’38.8” N	74°00’4.3” E	Circle
05	W5	15°24’29.4” N	74°01’12.7” E	Circle
06	W6	15°23’59” N	74°00’37” E	Circle
07	W7	15°23’6.5” N	73°59’59.8” E	Square
08	W8	15°24’38.4” N	74°00’26.8” E	Circle
09	W9	15°24’6.2” N	74°00’37.2” E	Circle
10	W10	15°23’5.6” N	74°00’15.4” E	Circle
11	W11	15°23’54.3” N	74°00’3.5” E	Semi-circle
12	W12	15°23’29.6” N	73°59’50.4” E	Circle
13	W13	15°24’19.5” N	74°00’31” E	Circle
14	W14	15°23’51.2” N	74°00’47.5” E	Semi-circle
15	W15	15°23’55.8” N	74°00’43.8” E	Circle

3.2.1 Field test

a] pH

The pH of water sample from 15 wells of Ponda city was measured in the field with a five Go-mettler Toledo portable pH meter. The portable pH meter was calibrated before going to field using standard solutions of pH 4, pH 7 and pH 10. The pH readings for each sample were obtained and recorded using following method.

Procedure

1} Remove the pH meter probe from the 3M KCl solution and rinse it with distilled water.

2} Switch on the pH meter. The monitor screen should show 7.00.

3} Then insert the tip of the probe into the water from the well to be tested, about half inch.

4} Hear the beep and note down the reading on the display.

5} The value displayed on the monitor is the pH of the water.

6} Rinse the probe with distilled water and immerse it again into a 3M KCl solution.

b] Electrical Conductivity.

The EC of water samples from 15 wells was determined with a solinst TLC EC meter in the field itself. The EC values was reported in the unit millisiemens (u) and it was done using following procedure.

Procedure

1} Rinse the probe with distilled water and switch on the EC meter by pressing the on/off button. The monitor screen should display the number 0.

2} Dip the probe into the well and listen for the beep sound when it comes in contact with the water.

3} Record the values on the screen. The number seen on the screen is the EC (Electrical Conductivity value) at the well surface.

3.3 POST FIELD DATA PROCESSING

The location was determined using GPS measurement (Global Positioning System) and wells were mapped on the base map using QGIS software. TDS values were calculated and pH, EC and TDS values were plotted on the base map and on their respective contours by the use of SURFER 27 software.

a) TDS was calculated as follows. (CGWB,2021)

TDS levels for calculated using the following formula

TDS (mg/l) = K*EC (us/cm)

(Where K is the proportionality constant i.e. 0.64).

3.3.1 Laboratory Test

Water samples were collected from 15 wells in Ponda city. The samples were collected in 500 ml Sterilized polythene bottles. Precautions were taken to prevent any contamination of water sample and standard analytical protocols (S.A P May 1999) were followed for their analysis. There was acidification of well water sample with concentrated nitric acid and kept in a refrigerator to ensure that the metals are in dissolved state. If HNO3 is not added some metals may oxidise and their detection becomes difficult.

A} Determination of hardness

a] Total Hardness (EDTA Titrimetric Method ID: 1.12 [S.A.P May 1999])

The Total Hardness was calculated by using following method.

Requirements – Beaker, conical flask-250 ml, burette, pipette, 0.02N EDTA, Eriochrome black T indicator, Ammonium chloride buffer solution, distilled water, dropper, spatula etc.

Reagent preparation

1} Preparation of 0.02 EDTA titrant – weigh 3.273 g of EDTA powder and dissolve it in 1000 ml of distilled water.

2} Preparation of Ammonium Buffer—weigh 16.9 g of Ammonium Chloride (NH4Cl) and dissolve it in 143 ml Ammonium Hydroxide (NH40H). Add 1.25 gram of Magnesium salt of EDTA to the solution and then dilute it up to 250 ml of distilled water.

3} Preparation of Eriochrome Black T indicator – weigh 0.5 gram of Eriochrome black T indicator in 80ml of 90% ethanol and add up to 100 ml with 95% ethanol.

Procedure

1} Wash the burette, pipette, conical flask and all other apparatus with distilled water.

2} Rinse and fill the burette with 0.02N EDTA solution.

3} Rinse and Pipette out 25 ml of water sample in a clean 250 ml conical flask and then add one ml Ammonium Buffer.

4} Add 2 to 3 drops of Eriochrome black T indicator and titrate it against 0.02 N EDTA solution.

5} The end point is determined by colour change from red to blue.

Formula

$$\text{Total hardness} = \frac{\text{ml of EDTA titrant} * 1 * 1000}{\text{ml of sample taken for titration}}$$

b] Determination of Calcium Hardness [EDTA titrimetric 1.29 (SAP)]

The Calcium Hardness was calculated by using the following method.

Requirement – Beaker, 250 ml conical flask, burette, pipette, dropper, glass rod, spatula, murexide indicator powder, 1N sodium hydroxide solution, 0.02 N EDTA solution, distilled water etc

Reagent preparation

1} Preparation of 0.02 N titrant – take 3.273 gram of EDTA powder and dissolve it in 1000 ml of distilled water.

2} Preparation of 1N sodium hydroxide solution – weigh 4.5 gram of sodium hydroxide in 100 ml distilled water and then allow it to cool.

Procedure

1} Wash the burette, pipette, conical flask and other apparatus with distilled water.

2} Rinse and fill the burette with 0.02 N EDTA solution.

3} Rinse and pipette out 25 ml of water sample in a clean 250 ml conical flask and add 2 ml of NaOH solution.

4} Add a pinch of murexide indicator powder to the sample solution and titrate it against 0.02 N EDTA solution.

5} The endpoint is determined by the colour change from pink to purple.

Formula-

$$\text{Calcium (as Ca)} - \text{mg/l} = \frac{\text{ml of EDTA Titrant} * 0.01 * 40.008}{\text{ml of the sample taken for titration}}$$

c] Determination of Magnesium hardness (calculation from Total Hardness and Calcium ID:1.36 [S.A.P May 1999]).

Formula

Mg in mg/l =TH as MgCaCO3/l – Calcium Hardness as CaCO3/l * 0.243

Where TH = total Hardness MgCaCO3.

B} Determination of Sodium (Na) And Potassium (K) Using Flame Photometer.

To analyse Sodium (Na) and Potassium (K), Flame Photometer was used. Flame Photometer is an instrument used to analyse cations and anions and is a type of atomic absorption spectroscopy.

Procedure

1} Prepare standard solution and keep the water samples ready for analysis using flame photometer.

2} Check if the gas, air, drain hose connection is correct.

3} Switch on the flame photometer and the compressor according to the guidelines.

4} Adjust the outlet pressure and place the capillary tube in distilled water.

5} Ignite the flame as soon as you turn on the gas supply.

6} Immerse the capillary tube in blank solution and aspirate blank solution for cleaning.

7} Then put the capillary tube in the sample solution and aspirate sample solution and record the readings for sodium (Na) and potassium (K).

8} Go through the device shutdown process.

C} Heavy Metal Analysis

Groundwater Samples were collected from different wells in Ponda city in the month of December 2023. Total 11 samples were collected in 500 ml sterilized polythene sample bottles and 10 drops of concentrated Nitric Acid (HNO_3) was added to the samples and kept in Refrigerator so that the heavy metals in the samples do not precipitate and stay in dissolved state. Then the samples were transferred in 200 ml sample bottles and given for analysis of 4 heavy Metals in Central Coastal Agricultural Research Institute (ICAR), Old Goa. The heavy metal analysis was done by Atomic Absorption Spectroscopy (AAS). The data was received in a tabular format. This data was further used for calculating water quality indices like Heavy Metal pollution Index (HPI) and Metal Index (MI) which in turn aided in health risk assessment of Ponda city.

Procedure –

a} HPI – Heavy Metal Pollution Index

It gives the impact of heavy metal on water quality (Vasant Wagh et al., 2018). HPI can be calculated by using some formula listed below

HPI =∑ WiQi/ ∑Wi

Where Wi = unit weight of the i'th parameter and Qi = sub index value for the i'th parameter.

A} To calculate Wi, the formula is -

Wi = k/Si

Where Wi = unit weight of i'th parameter, k= constant, Si= standard permissible limit value for the i'th parameter.

To calculate k, we use the following formula-

$$K = 1/(\sum 1/Si)$$

$$\sum 1/Si = 1/S1+1/S2+1/S3+\ldots\ldots\ldots\ldots+1/Sn$$

Where S_1, S_2, S_3 are the standards for different heavy metals.

B} To calculate Qi, we use following formula-

$$Qi = \sum \frac{| Mi - Ii |}{(Si - Ii)} * 100$$

Where Mi is the heavy metal concentration obtained after analysis, Ii is the ideal value of the i'th parameter and Si is the standard value for the i'th parameter.

For calculations, iron (Fe) permissible limit is required, so the max. permissible limit of 1 mg/l is taken from ICMR standards (2021). And the acceptable limit is taken as 0.3 mg/l as mentioned by BIS (2012).

b} MI- Metal Index

It is the pollution evaluation Index which gives the severity of the contamination. (Anjali Nayak et al., 2023). MI can be calculated by using following formula –

MI = ∑ Hc/Hmac

Where H_c is the monitored value of the i'th parameter and H_{mac} is the maximum admissible/permissible concentration of the i'th parameter.

3} Water Quality Index (WQI)

Based on a number of water quality factors, the Water Quality Index (WQI) gives a single figure that represents the general state of the water at a certain place and moment (Rajesh Prajapati and Ram Bilas.,2018). Formulae and steps for calculating WQI are listed below –

Step 1 – Calculate the unit weight (Wn) factor for each parameter by using the formula below

Wn = k/Sn   where, K = 1/(∑1/Sn).

Sn = Standard value of the n’th parameter

On summation of all selected parameters unit weight factor (Wn) we get 1(unity).

Step 2 – Calculate the Sub index value using the following formula

$$Qn = \frac{[(Vn-Vo)]}{[(Sn-Vo)]} * 100$$

Where Vn = mean concentration of n’th parameter.

Sn = Standard desirable values of the n’th parameter.

Vo = actual values of the parameter in pure water (generally Vo = 0 for all parameter except for pH).

$$QpH = \frac{[(VpH-7)]}{[(8.5-7)]} * 100$$

Step 3 – Combining step 1 and 2, WQI is calculated

$$\text{Overall WQI} = \frac{\sum WnQn}{\sum Wn}$$

CHAPTER 4: ANALYSIS AND CONCLUSION

4.1 HYDROGEOLOGICAL INVESTIGATION

Hydrogeology is the study of water and its interaction with the geological characteristics and geomorphology (M. Ibrampurkar., 2012). Groundwater is created when water seeps into the earth and becomes a vital supply of pure, uncontaminated water. The geological formation's porosity and permeability affect groundwater circulation.

Groundwater is a replenishable resource, but over usage lowers its quality and quantity, hence groundwater monitoring is crucial. A groundwater flow net can be used for this. These flow nets show how water moves deeply into rocks or soil. Water moves from an elevation that is higher to one that is lower. We can determine the direction of groundwater flow by observing that the equipotential lines are perpendicular to the flow lines.

To find well locations with high-quality groundwater suitable for certain uses such as drinking, irrigation, household use, and industrial use, hydrogeological research is conducted. Water quality needs to be monitored since contaminants travel with underground water. It also aids in finding acceptable locations for the disposal of garbage. (B. B. S. Singhal and R. P. Gupta, 1999).

4.1.1 Interpretation of Groundwater flow regime

Flow net analysis

During the post-monsoon period, a groundwater flow net was created for Ponda city using groundwater level data collected in December 2023 with Surfer 27 software, as depicted in Figure 4.1. The groundwater level above mean sea level was determined by using the elevation from Google Earth Pro and the groundwater level depth measured from the surface. An illustration of two-dimensional steady-state groundwater movement through aquifers is called a flow net. Groundwater flows from the southeastern region to the northwestern region, ultimately discharging into the Zuari river, following a gradient from higher to lower elevations. The equipotential lines in the North Western area are closely spaced, indicating a steep slope and rapid groundwater flow, whereas the equipotential lines in the South Eastern area are widely spaced, indicating a smooth slope and steady flow.

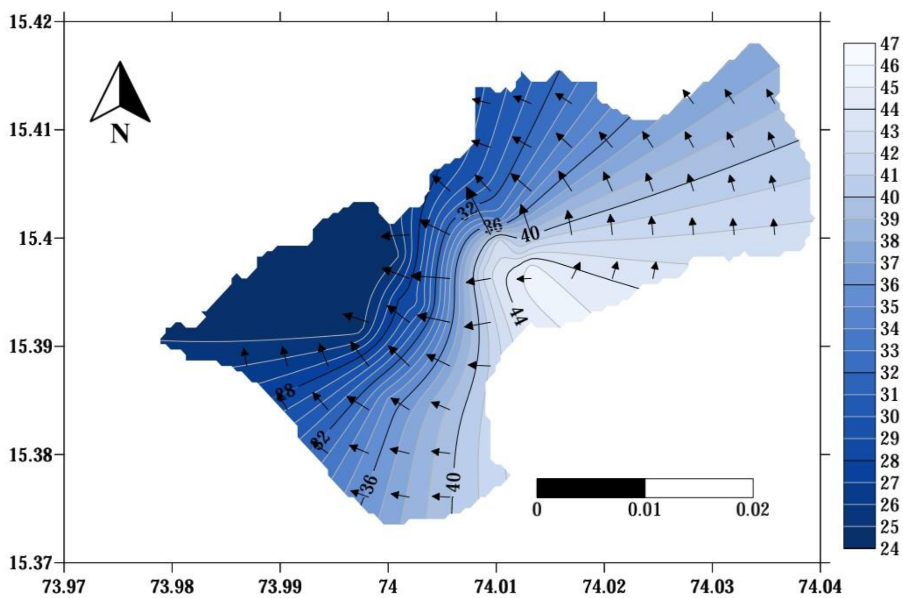

Figure 4.1: Flow net of Study Area in December 2023

4.1.2 Depth to groundwater levels below ground

The depth to the groundwater was measured from the ground surface during post monsoon in Ponda city is shown in table 4.1. The depth to groundwater measured from the ground surface in different wells in the study area is shown in figure 4.2. The average depth of groundwater below the ground in the study area is 4.31 m. Majority of wells in the study area region are found at shallow levels with exception of W3 (6.88m), W8 (7.90m) and W10 (8.83m) which are having comparatively more depth.

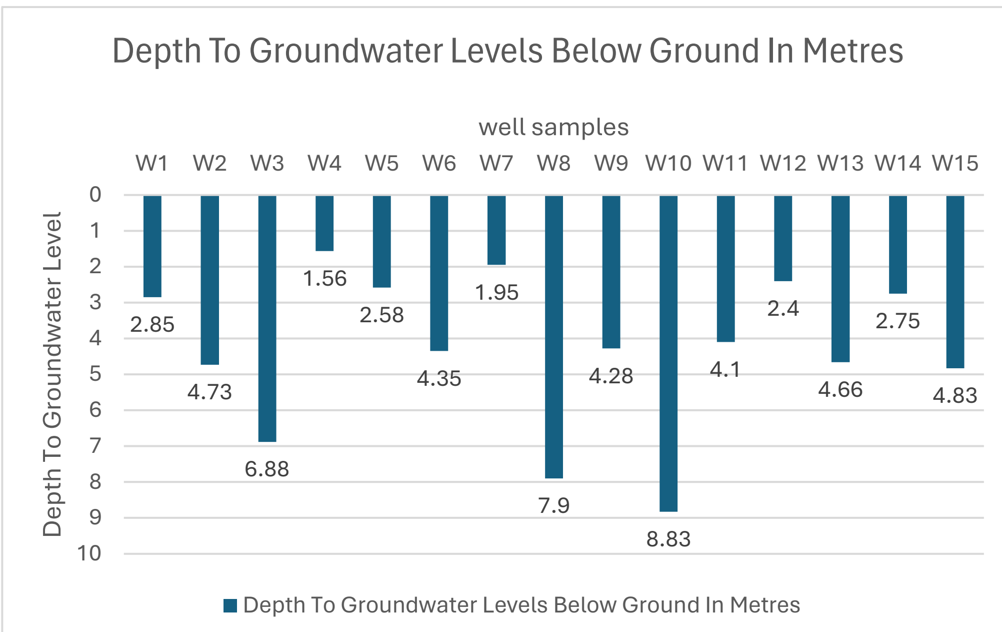

Figure 4.2: Variation In Depth of groundwater level from the surface

Table 4.1: Depth to groundwater levels below ground

Well samples	Latitude (DMS)	Longitude (DMS)	Depth to Groundwater levels below ground (m).
W1	15°24’05.5” N	74°00’18.6 E	2.85
W2	15°23’47.9” N	74°00’31.9” E	4.73
W3	15°23’37.9” N	74°00’10.6” E	6.88
W4	15°23’38.8” N	74°00’4.3” E	1.56
W5	15°24’29.4” N	74°01’12.7” E	2.58
W6	15°23’59” N	74°00’37” E	4.35
W7	15°23’6.5” N	73°59’59.8” E	1.95
W8	15°24’38.4” N	74°00’26.8” E	7.90
W9	15°24’6.2” N	74°00’37.2” E	4.28
W10	15°23’5.6” N	74°00’15.4” E	8.83
W11	15°23’54.3” N	74°00’3.5” E	4.10
W12	15°23’29.6” N	73°59’50.4” E	2.40
W13	15°24’19.5” N	74°00’31” E	4.66
W14	15°23’51.2” N	74°00’47.5” E	2.75
W15	15°23’55.8” N	74°00’43.8” E	4.83

4.1.3 Thickness of water column

The thickness of water column during post monsoon in Ponda city is displayed on table 4.2. The variation of water column thickness among the wells in study area is shown in figure 4.3. The average water column thickness in Ponda city during post monsoon was 1.65m. The water column thickness is thin in most of the wells where W15 (3.2m) has the most water column thickness and W9 (0.6m) has the least water column thickness. The water column is less as the samples are collected in post monsoon.

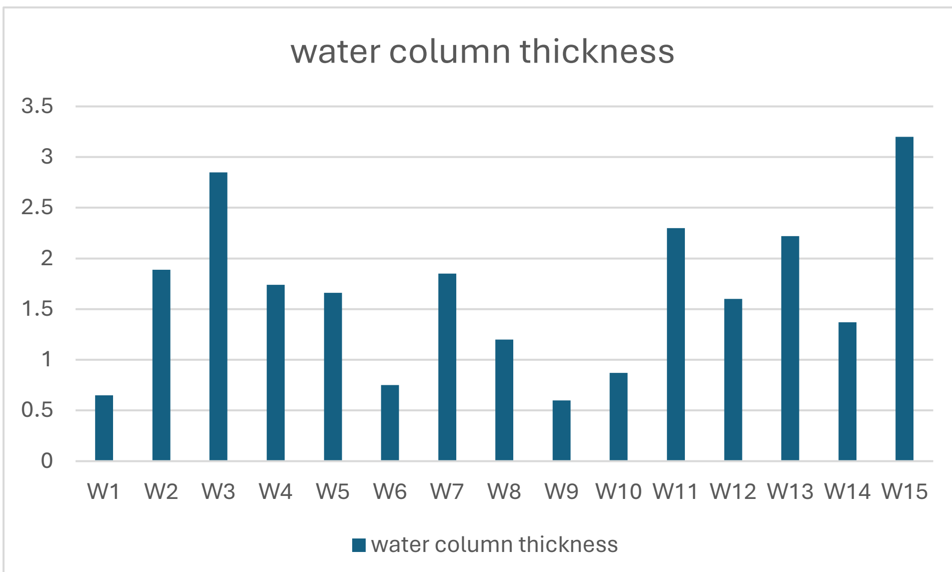

Figure 4.3: Variation in water column thickness

Table 4.2: Thickness of water column

Well samples	Latitude (DMS)	Longitude (DMS)	Thickness of water column (m)
W1	15°24’05.5” N	74°00’18.6 E	0.65
W2	15°23’47.9” N	74°00’31.9” E	1.89
W3	15°23’37.9” N	74°00’10.6” E	2.85
W4	15°23’38.8” N	74°00’4.3” E	1.74
W5	15°24’29.4” N	74°01’12.7” E	1.66
W6	15°23’59” N	74°00’37” E	0.75
W7	15°23’6.5” N	73°59’59.8” E	1.85
W8	15°24’38.4” N	74°00’26.8” E	1.2
W9	15°24’6.2” N	74°00’37.2” E	0.6
W10	15°23’5.6” N	74°00’15.4” E	0.87
W11	15°23’54.3” N	74°00’3.5” E	2.3
W12	15°23’29.6” N	73°59’50.4” E	1.6
W13	15°24’19.5” N	74°00’31” E	2.22
W14	15°23’51.2” N	74°00’47.5” E	1.37
W15	15°23’55.8” N	74°00’43.8” E	3.2

4.1.4 Total depth of wells below ground

The total depth of wells below ground for Ponda city during post monsoon in the month of December 2023 is represented in table 4.3. The wells in study area have a Lateritic aquifer underneath. There is variation seen in total well depth based on groundwater level. The total well depth of W3 (9.73m), W8 (9.10m), W10 (9.70m) and W15 (8.03m) have higher well depth in the study area.

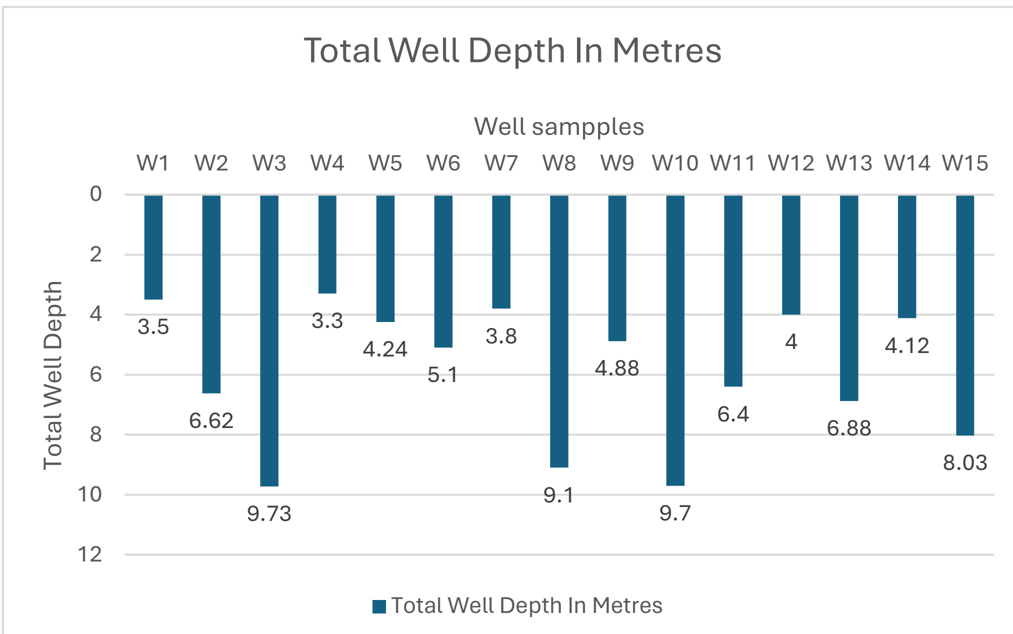

Figure 4.4: Variation in Total Well Depth

Table 4.3: Total well depth

Well samples	Latitude (DMS)	Longitude (DMS)	Total Well Depth (m)
W1	15°24’05.5” N	74°00’18.6 E	3.50
W2	15°23’47.9” N	74°00’31.9” E	6.62
W3	15°23’37.9” N	74°00’10.6” E	9.73
W4	15°23’38.8” N	74°00’4.3” E	3.30
W5	15°24’29.4” N	74°01’12.7” E	4.24
W6	15°23’59” N	74°00’37” E	5.10
W7	15°23’6.5” N	73°59’59.8” E	3.80
W8	15°24’38.4” N	74°00’26.8” E	9.10
W9	15°24’6.2” N	74°00’37.2” E	4.88
W10	15°23’5.6” N	74°00’15.4” E	9.70
W11	15°23’54.3” N	74°00’3.5” E	6.40
W12	15°23’29.6” N	73°59’50.4” E	4.00
W13	15°24’19.5” N	74°00’31” E	6.88
W14	15°23’51.2” N	74°00’47.5” E	4.12
W15	15°23’55.8” N	74°00’43.8” E	8.03

4.2 WATER QUALITY ASSESSMENT

Groundwater is major source of drinking water and it is used for many other purposes like household, agricultural and industrial needs. Maintaining good water quality is major concern as the water quality is degrading with time due to contamination from anthropogenic activities like sewage disposal, urbanisation, high population and over use of fertilizers. (Gurdeep Singh and Rakesh Kant Kamal., 2016).

Presence of heavy metal in groundwater is major issue faced and this is mainly due to increasing population which leads to urbanisation and industrialization. Mining also contributes to rise of heavy metals in groundwater. So Regular monitoring of groundwater quality is essential for reduction of health implications caused by consumption of poor water quality. This can also help in prevention of contamination in the groundwater.

The assessment was carried out by using physical and chemical parameters. The physical parameters include pH, Total dissolved solids (TDS), and Electrical conductivity (EC). The chemical parameters include total hardness estimation and concentration of Calcium (Ca) and Magnesium (Mg), and cations like Sodium (Na) and Potassium (K). Heavy metals like iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) are also analysed.

4.2.1 Physical Parameter

a) pH

The pH of 15 water samples in the study area was recorded by using FiveGo-mettler Toledo portable pH meter during December 2023. The permissible limit of pH for drinking water is 6.5 to 8.5 according to the Bureau of Indian Standards (BIS, 2012). The pH of the wells in the study area is shown in the table 4.4. The variation of pH in the study area is depicted in the figure 4.7. The elevated pH can be due to alkaline substances present in geological formations rich in minerals like limestone and dolomite. It can increase due to concrete runoff, agricultural runoff and industrial discharge. pH can be influenced by temperature, rainfall and vegetation cover. Low pH can be due to deforestation which causes soil erosion and release of organic acids. It can decrease due to release of acidic fertilisers and acidic chemicals from industrial discharge. Leaching of acidic substances lowers the pH.

Observation:

Only 3 samples i.e. W12, W13, and W14 out of 15 samples are in the permissible limit with regards to BIS (2012). The remaining 12 samples were acidic and not fit for consumption. There was no alkaline water sample found in the study area. The highest pH in the study area was found in W14 (6.57) and the lowest pH in the study area was found in W7 (5.34). The average pH in the study area was 6.056.

Table 4.4: Values of pH in study area

Well samples	Latitude	Longitude	pH values
W1	15.4015369	74.0051531	6.16
W2	15.3966295	74.0088603	6.27
W3	15.3938699	74.0029390	6.16
W4	15.3941227	74.0012063	6.20
W5	15.4081608	74.0201977	6.15
W6	15.3997220	74.0102780	5.96
W7	15.3851265	73.9999406	5.34
W8	15.4106610	74.0074320	6.16
W9	15.4017195	74.0103214	5.85
W10	15.3848873	74.0042710	5.53
W11	15.3984083	74.0009790	5.66
W12	15.3915593	73.9973422	6.52
W13	15.4054225	74.0085988	6.55
W14	15.3975610	74.0132078	6.57
W15	15.3988249	74.0121587	5.76

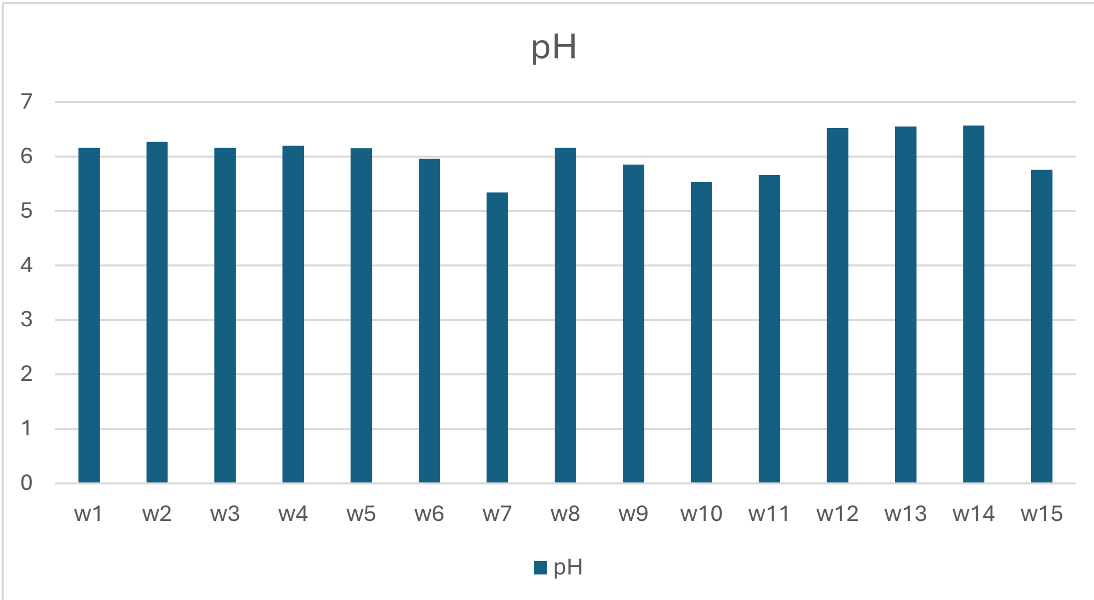

Figure 4.5: Variation of pH in different wells in the study area

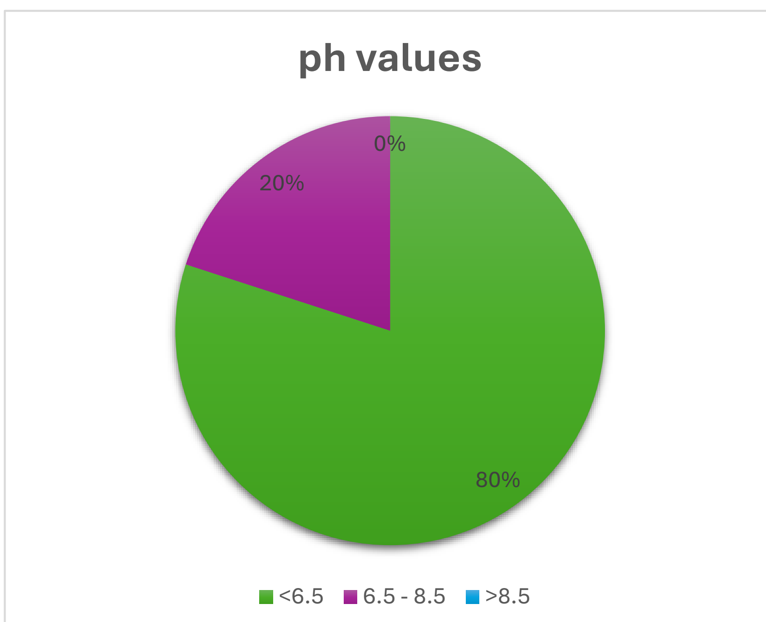

Figure 4.6: Ph Values Categorization according to BIS Standards (2012)

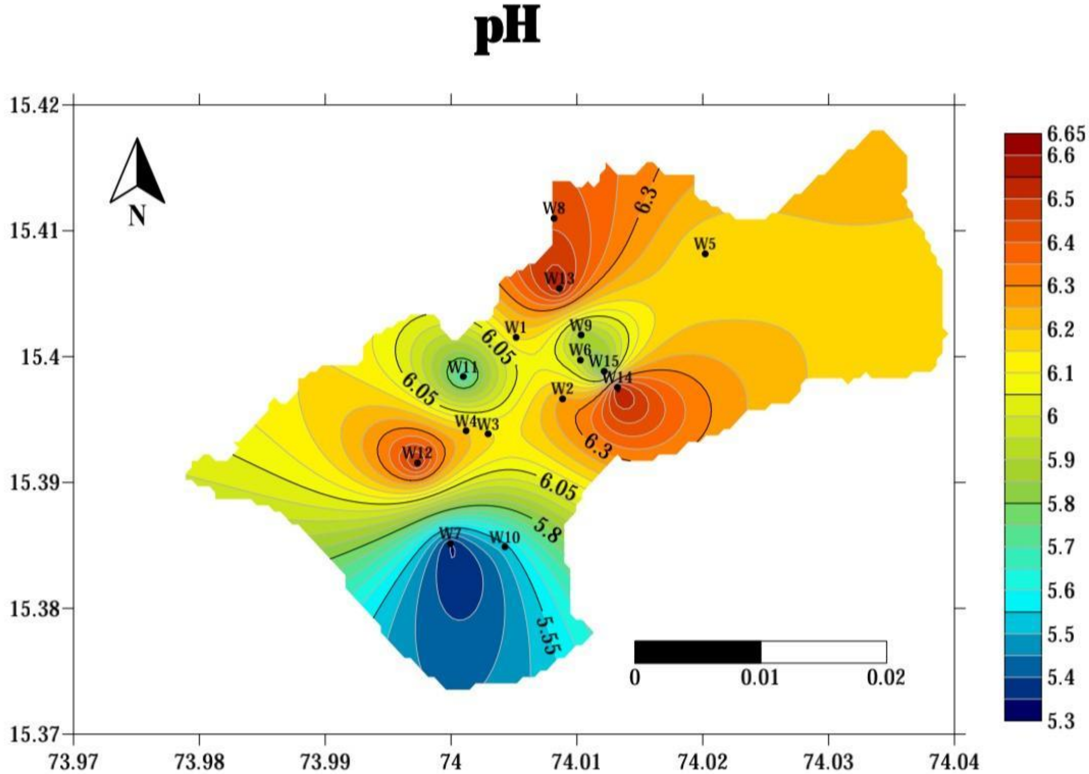

Figure 4.7: Contour Distribution of PH during December 2023

Inference: 12 wells out of 15 were acidic, this may be due to atmospheric deposition of acidic pollutants. Dry deposition of pollutants such as sulphur dioxide and nitrogen oxides from industrial activities and vehicular emissions may accumulate on the land surface during the monsoon season and be washed into water bodies during the post-monsoon period, contributing to a decrease in pH levels. Microbial activity in the subsurface can produce acidic byproducts through processes like organic matter decomposition or sulphate reduction, contributing to low pH levels in groundwater.

b) Electrical Conductivity (EC)

The unit used to determine the electrical conductivity is siemens per metre (S/m) or Microsiemens per centimetre (μS/cm). The EC of water samples were determined in the study area during post monsoon. The table 4.5 shows the EC values in the study area. The variation in EC in the study area is displayed in figure 4.10.

The EC is usually related to the total dissolved solids (TDS), Higher the TDS, higher the EC. The increase in EC in groundwater can be due to industrial waste or agricultural waste water, urban runoff or chemical used in water treatment process. To measure the salinity or TDS we generally use Electrical Conductivity values. There is no limit set by BIS for Electrical conductivity, but the EC value should not exceed the limit of 400 μS/cm according to World Health Organization (WHO, 2007).

Observation

Two Samples from W5 and W8 exceeded the limit of EC recommended by WHO (2007). The remaining samples were within the limit of 400 μS/cm. The highest EC was observed In W8 (895 μS/cm) whereas the lowest EC was observed in W7 (69 μS/cm). The average EC In the study area was 232.53 μS/cm. Waste from the industries that has not been treated will eventually seep into groundwater and can cause an increase in EC.

Table 4.5: EC values in the study area

Well samples	Latitude	Longitude	EC VALUES in µS/cm
W1	15.4015369	74.0051531	289
W2	15.3966295	74.0088603	94
W3	15.3938699	74.0029390	282
W4	15.3941227	74.0012063	165
W5	15.4081608	74.0201977	475
W6	15.3997220	74.0102780	171
W7	15.3851265	73.9999406	69
W8	15.4106610	74.0074320	895
W9	15.4017195	74.0103214	179
W10	15.3848873	74.0042710	117
W11	15.3984083	74.0009790	181
W12	15.3915593	73.9973422	124
W13	15.4054225	74.0085988	138
W14	15.3975610	74.0132078	123
W15	15.3988249	74.0121587	186

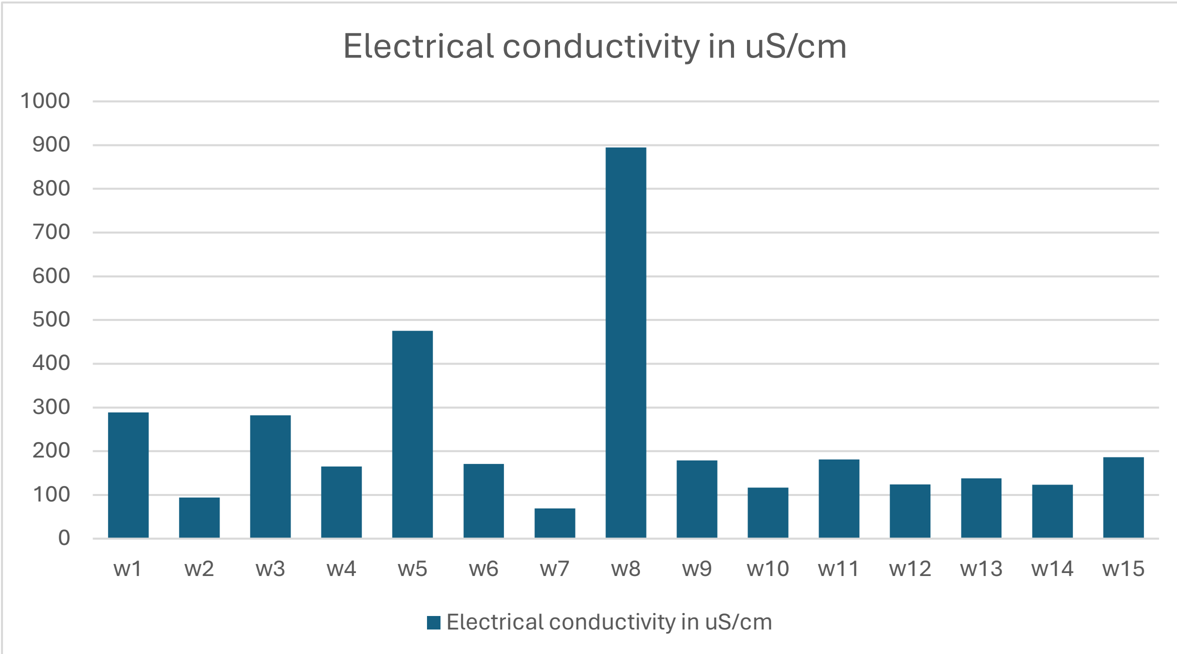

Fig 4.8: Variation of EC in different wells of the study area

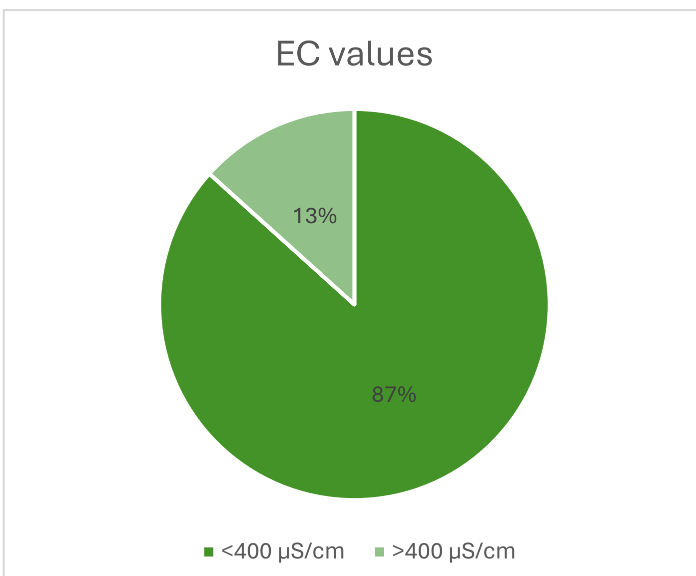

Fig 4.9: EC categorization according to WHO (2007) limits.

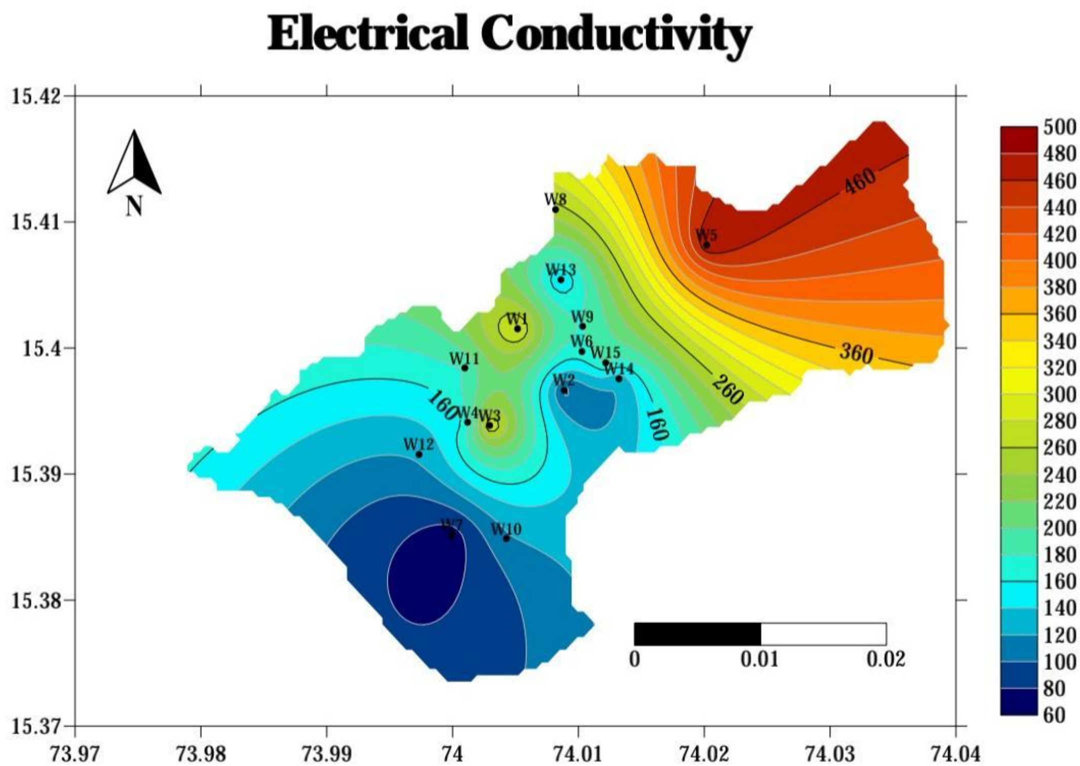

Figure 4.10: Contour Distribution map showing EC

Inference:

Samples from W5 and W8 had high TDS. Plantation of different vegetables and fruits were there in vicinity of W5, the use of fertilizers, particularly those containing soluble salts like potassium nitrate or ammonium sulphate can increase EC levels in groundwater through leaching from the soil into the aquifer. W8 was contaminated with plastic bottles and other waste products which can decay in well and increase the EC.

c) Total Dissolved Solids (TDS)

TDS is the total amount of inorganic and organic materials dissolved in water. The unit of TDS is parts per million (ppm) or milligram per litre (mg/l). TDS is calculated by using the EC Measurements. The acceptable limit of TDS according to Bureau of Indian Standards (BIS, 2012) is 500 mg/l, and the maximum permissible limit for TDS is 2000 mg/l. The table 4.6 represented the TDS values in the study area. The variation in TDS in the study area is shown in figure 4.12.

Observation

All the well samples had TDS values less than the acceptable limit of 500 mg/l, except for well 8 which had higher TDS (572.8 ppm). The wells W2, W7, W10, W12, W13 and W14 showed TDS values less then 100mg/l. The average TDS value for the study area was 148.82 ppm. The TDS in the study area was in the range of 44.16 ppm (W7) to 572.8 ppm (W8).

Inference:

The high TDS can be due lithology of soil and it also depends on presence of dissolved minerals. The weathering of rocks and minerals in the subsurface can release dissolved ions into groundwater, increasing its TDS content. Alterations in land use, such as deforestation, urbanization, and agricultural expansion, can affect the hydrological cycle and increase the transport of dissolved solids into groundwater. Changes in land use practices can lead to higher TDS concentrations in groundwater over time. High TDS can lead to kidney stones.

Table 4.6: TDS Values in Study Area

Well samples	Latitude	Longitude	TDS in ppm
W1	15.4015369	74.0051531	184.96
W2	15.3966295	74.0088603	60.16
W3	15.3938699	74.0029390	180.48
W4	15.3941227	74.0012063	105.6
W5	15.4081608	74.0201977	304
W6	15.3997220	74.0102780	109.44
W7	15.3851265	73.9999406	44.16
W8	15.4106610	74.0074320	572.8
W9	15.4017195	74.0103214	114.56
W10	15.3848873	74.0042710	74.88
W11	15.3984083	74.0009790	115.84
W12	15.3915593	73.9973422	79.36
W13	15.4054225	74.0085988	88.32
W14	15.3975610	74.0132078	78.73
W15	15.3988249	74.0121587	119.04

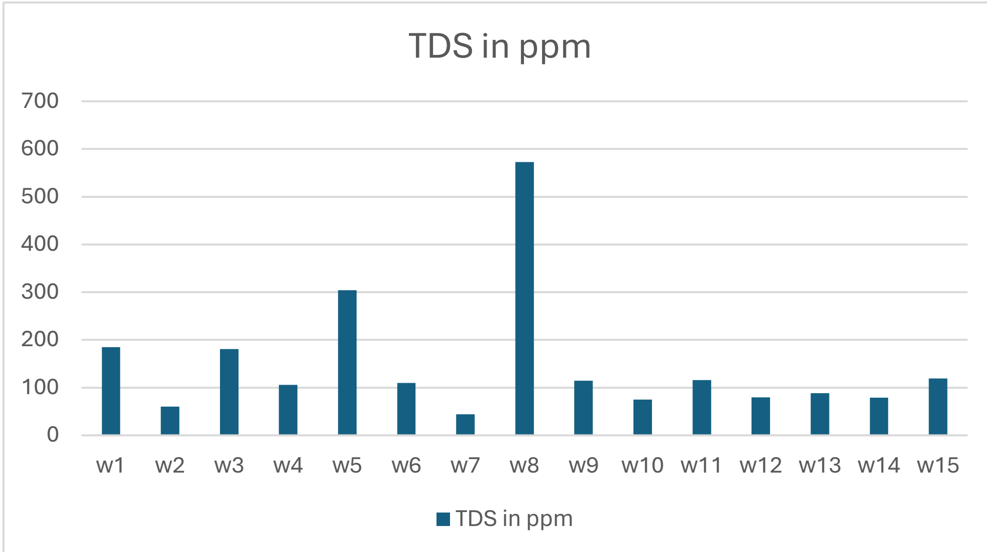

Figure 4.11: Variation of TDS in different wells in the study area

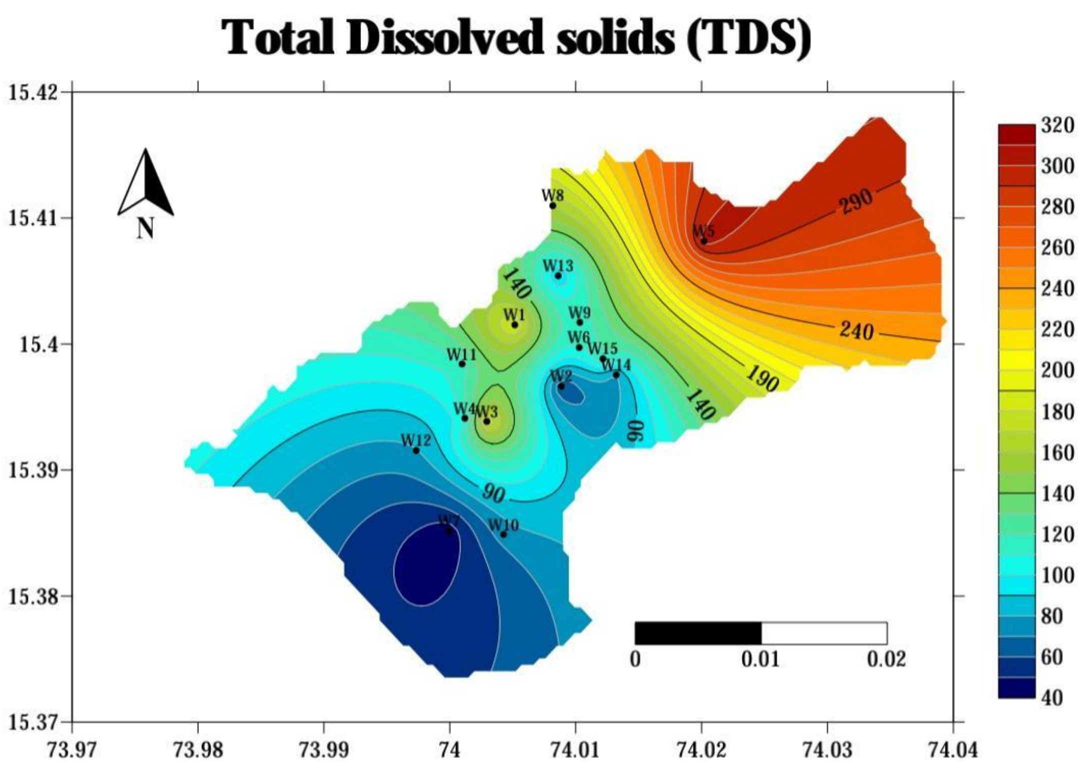

Figure 4.12: Contour Distribution Map showing TDS

4.2.2 Chemical Parameters

a) Total Hardness

The total hardness is the calcium and magnesium concentrations combined together in water. The weathering of rocks and soils in the aquifer can release dissolved calcium and magnesium ions into groundwater, contributing to hardness. The use of fertilizers containing calcium and magnesium compounds can increase the hardness of groundwater through leaching from the soil into the aquifer. Discharge from industrial processes, such as mining, manufacturing, and chemical production, can introduce calcium and magnesium ions into groundwater, raising its hardness levels. The total hardness is measured in Milligram per litre (mg/l) Or Parts Per million (ppm). The acceptable limit for total hardness (as CaCO3) is 200 mg/l and the maximum permissible limit is 600 mg/l according to BIS 2012. Using EDTA Titrimetric Method; ID: 1.29 S.A.P 1999, Total hardness was calculated. The table 4.7 represented the Total Hardness values in the study area. The variation in total hardness in the study area is shown in the figure 4.15.

Observation

All the samples were within the acceptable limit of 200mg/l. According to USGS classification (2018), only well W7 had soft water (0-60 mg/l), 11 wells i.e. W2, W3, W4, W5, W6, W9, W10, W11, W12, W14, W15 were having moderate hardness (61-120mg/l), and 3 wells i.e. W1, W8 and W13 were having presence of hard water (120-180mg/l). There were no wells with very high hardness (more the 180mg/l). The range of total hardness varies from 60mg/l (W7) to 156mg/l (W1). The average total hardness in the study area is 93.87 mg/l.

Table 4.7: Total hardness in study area

Well samples	Latitude	Longitude	Total Hardness
W1	15.4015369	74.0051531	156
W2	15.3966295	74.0088603	84
W3	15.3938699	74.0029390	112
W4	15.3941227	74.0012063	72
W5	15.4081608	74.0201977	64
W6	15.3997220	74.0102780	76
W7	15.3851265	73.9999406	60
W8	15.4106610	74.0074320	152
W9	15.4017195	74.0103214	80
W10	15.3848873	74.0042710	72
W11	15.3984083	74.0009790	72
W12	15.3915593	73.9973422	72
W13	15.4054225	74.0085988	124
W14	15.3975610	74.0132078	92
W15	15.3988249	74.0121587	120

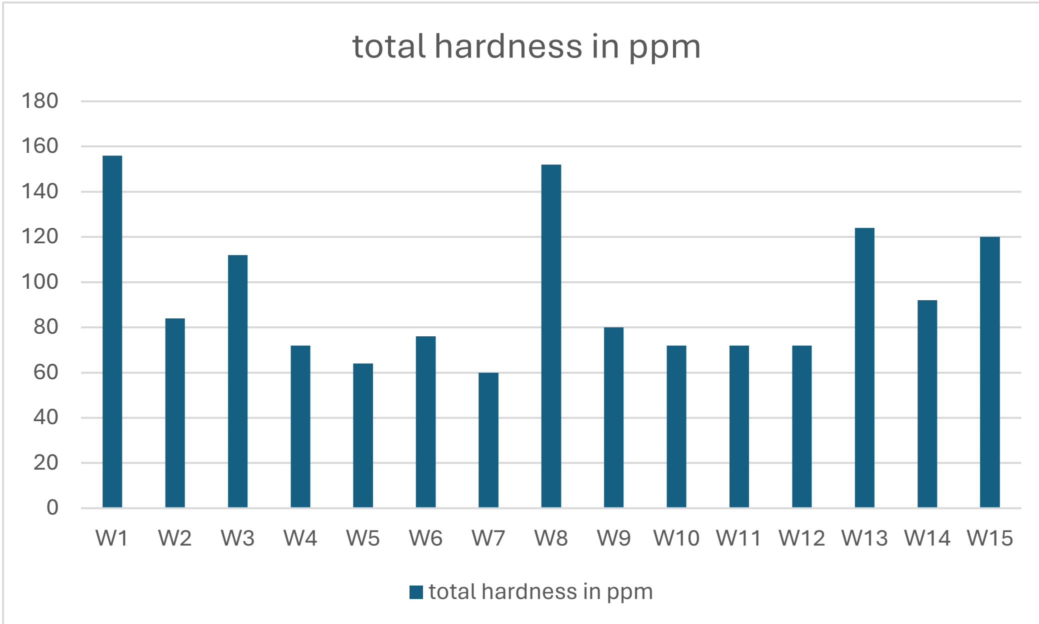

Fig 4.13: Variation in Total Hardness in the study area.

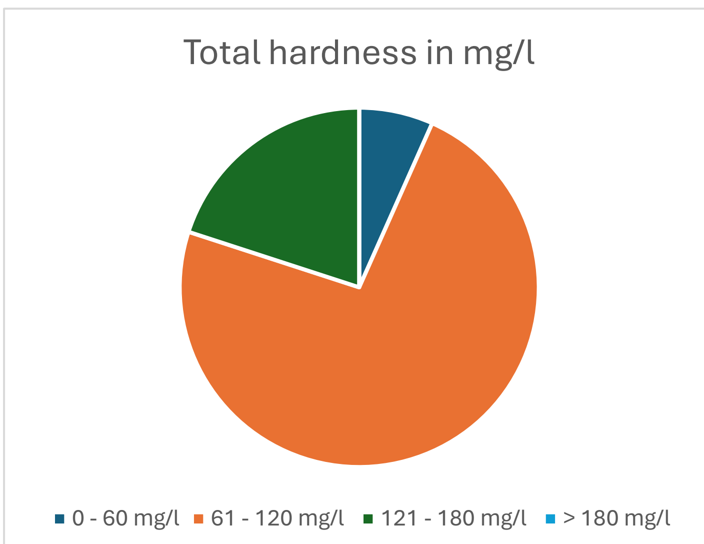

Fig 4.14: Total Hardness categorization based on USGS.

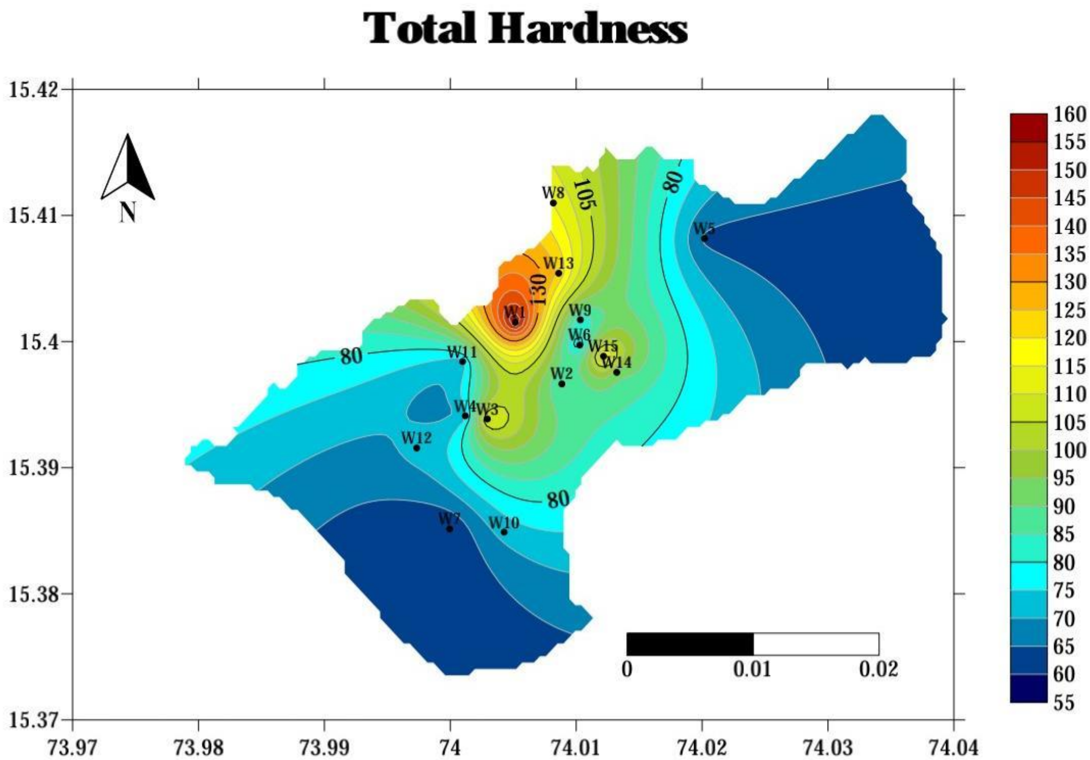

Figure 4.15: Contour distribution map showing Total hardness

b) Calcium (Ca)

Calcium enters into the groundwater primarily by the dissolution of carbonate rocks like limestone, dolomite etc. The calcium is measured by the unit ppm or mg/l. The maximum permissible limit of calcium is 200mg/l and the acceptable limit for calcium is 75 mg/l as said by BIS 2012. The standard procedure was followed for measuring Calcium [EDTA Titrimetric: 1.29 (S.A.P., May 1999)]. The table 4.8 gives the concentration of calcium in study area. The variation in Calcium hardness is displayed in figure 4.17.

Observation

All the well samples are within the acceptable limit of 75mg/l. The range of calcium in wells varies from 4.8 mg/l (W10 and W12) to 35.21 mg/l (W8). The average Ca content in the study region was 12.59 mg/l. High Calcium in drinking water can lead to constipation, diarrhoea and bloating.

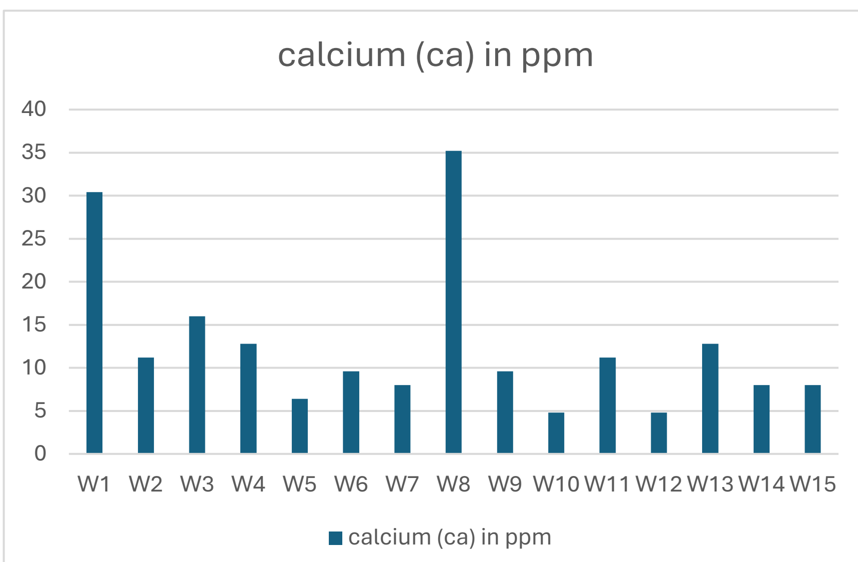

Fig 4.16: Variation in Calcium content in different wells in the study area

Table 4.8: Calcium Hardness in Study Area

Well samples	Latitude (DMS)	Longitude (DMS)	Calcium (Ca) in ppm
W1	15°24’05.5” N	74°00’18.6 E	30.40608
W2	15°23’47.9” N	74°00’31.9” E	11.20224
W3	15°23’37.9” N	74°00’10.6” E	16.0032
W4	15°23’38.8” N	74°00’4.3” E	12.80256
W5	15°24’29.4” N	74°01’12.7” E	6.40128
W6	15°23’59” N	74°00’37” E	9.60192
W7	15°23’6.5” N	73°59’59.8” E	8.0016
W8	15°24’38.4” N	74°00’26.8” E	35.20704
W9	15°24’6.2” N	74°00’37.2” E	9.60192
W10	15°23’5.6” N	74°00’15.4” E	4.80096
W11	15°23’54.3” N	74°00’3.5” E	11.20224
W12	15°23’29.6” N	73°59’50.4” E	4.80096
W13	15°24’19.5” N	74°00’31” E	12.80256
W14	15°23’51.2” N	74°00’47.5” E	8.0016
W15	15°23’55.8” N	74°00’43.8” E	8.0016

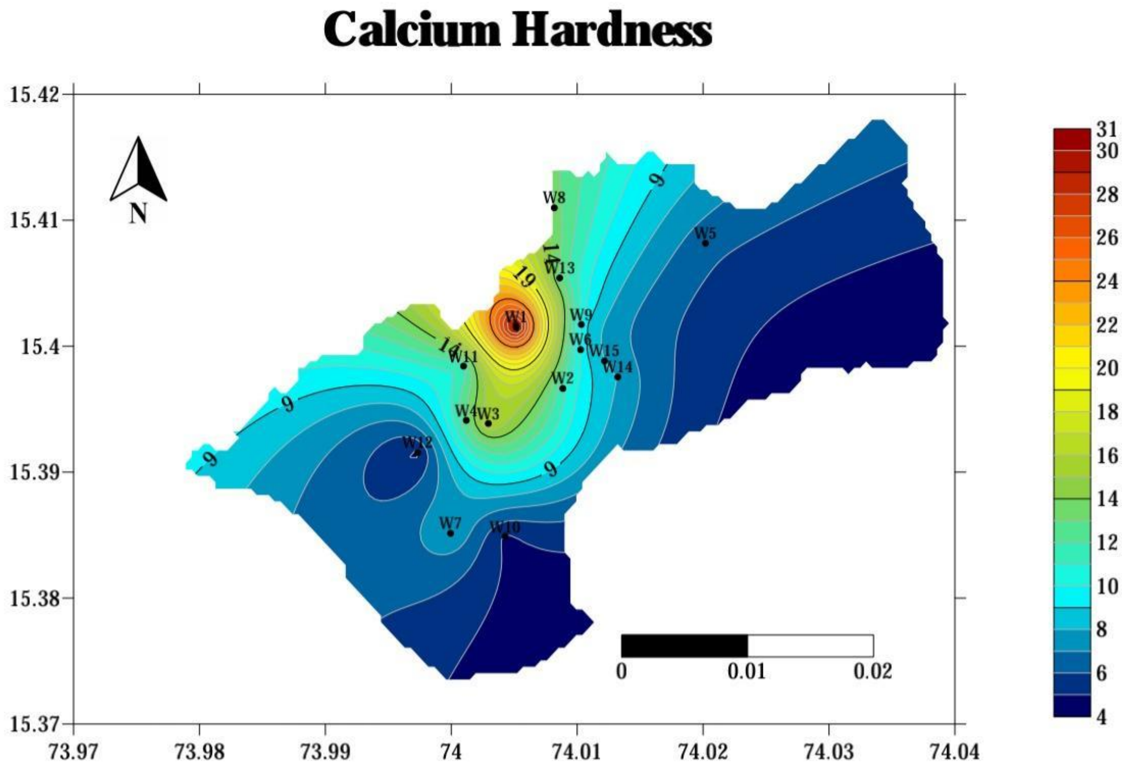

Figure 4.17: Contour distribution map showing Calcium hardness

c) Magnesium (Mg)

Magnesium (Mg) is found in the groundwater due to presence of carbonate rich rocks in the earth surface. The Magnesium hardness can be calculated by using the values of total hardness and calcium hardness. The Magnesium (Mg) is measured in ppm or mg/l. The maximum permissible limit for Magnesium is 100 mg/l and the acceptable limit for Magnesium is 30 mg/l according to BIS 2012. The table 4.9 represents the Magnesium concentration in the study area. The variation in Magnesium hardness is shown in the figure 4.19.

Observation

All the water samples were within the range of permissible limit of 100 mg/l (BIS 2012). All samples were within the acceptable limit of 30 mg/l (BIS 2012) except for W1 which has higher Magnesium hardness (30.52mg/l). The range of Magnesium hardness varies from 12.64 mg/l (W7) to 30.52 mg/l (W1). The average Mg hardness in the study region is 19.75 mg/l. High magnesium causes disruption in bowel habits.

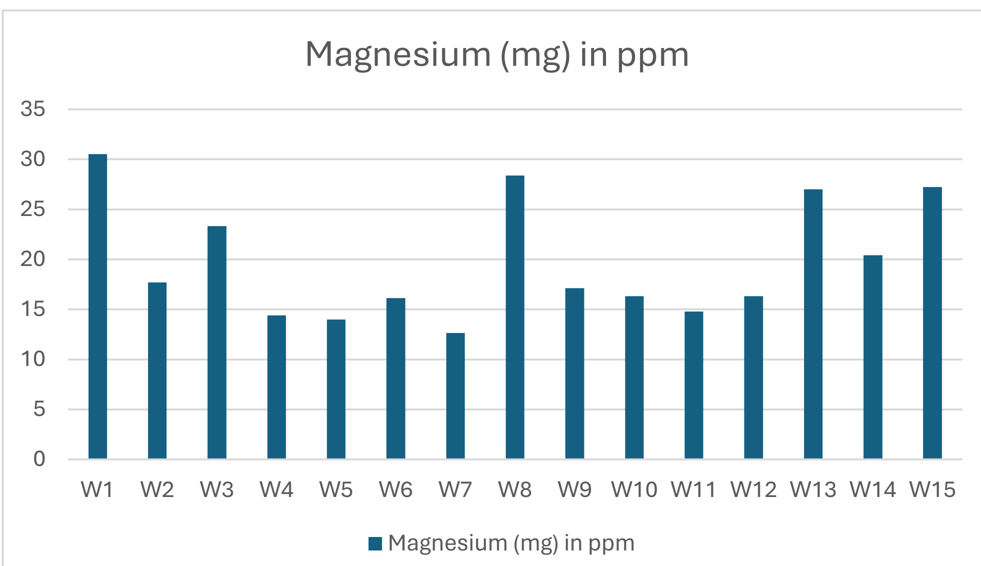

Fig 4.18: Variation in Magnesium content in different wells in study area

Table 4.9: Magnesium Hardness in Study Area

Well samples	Latitude (DMS)	Longitude (DMS)	Magnesium (mg) in ppm
W1	15°24’05.5” N	74°00’18.6 E	30.51932256
W2	15°23’47.9” N	74°00’31.9” E	17.68985568
W3	15°23’37.9” N	74°00’10.6” E	23.327224
W4	15°23’38.8” N	74°00’4.3” E	14.38497792
W5	15°24’29.4” N	74°01’12.7” E	13.99648896
W6	15°23’59” N	74°00’37” E	16.13473344
W7	15°23’6.5” N	73°59’59.8” E	12.6356112
W8	15°24’38.4” N	74°00’26.8” E	28.38068928
W9	15°24’6.2” N	74°00’37.2” E	17.10673344
W10	15°23’5.6” N	74°00’15.4” E	16.32936672
W11	15°23’54.3” N	74°00’3.5” E	14.77385568
W12	15°23’29.6” N	73°59’50.4” E	16.32936672
W13	15°24’19.5” N	74°00’31” E	27.02097792
W14	15°23’51.2” N	74°00’47.5” E	20.4116112
W15	15°23’55.8” N	74°00’43.8” E	27.2156112

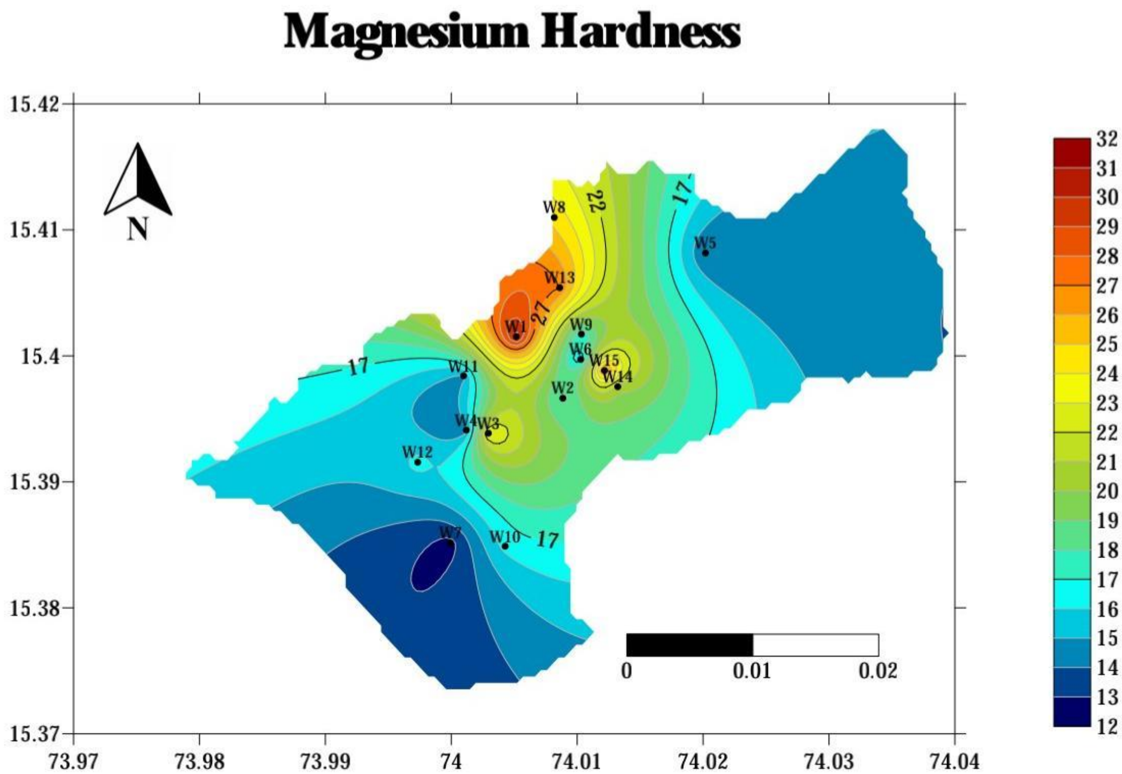

Figure 4.19: Contour Distribution map showing Magnesium Hardness

d) Sodium (Na) and Potassium (k)

The Sodium (Na) and Potassium (K) is distributed widely in nature. Sodium (Na) and Potassium (K) is measured in Parts Per Million (ppm). The Sodium (Na) content in the drinking water should be less than 200 mg//l and maximum permissible limit of Potassium (k) is 12 mg/l according to WHO (2017). Sodium can increase due to sewage effluents and mineral deposits. Potassium can increase due to addition of potassium fertilisers in the vicinity.

Observation for Sodium (Na)

The table 4.10 represents the Sodium concentration in the study area. The variation in the Sodium concentration in the study area is shown in figure 4.21. The Sodium concentration is ranging from 4.7 ppm (W7) to 24.2 ppm (W6). All the well samples are within the permissible limit of 200 mg/l as recommended by WHO (2017). The average Na content in the study area is 12.15 ppm. High intake of Sodium can cause vomiting, convulsions, muscular twitching and rigidity.

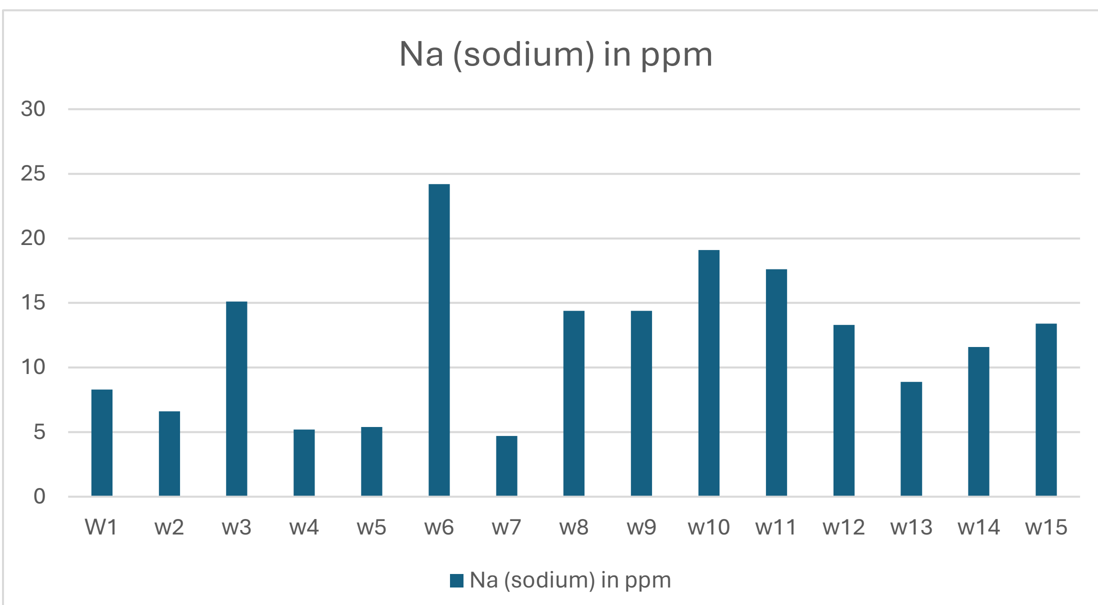

Fig 4.20: Variation of Sodium in study area

Table 4.10: Sodium **(**Na) Concentration in study area

Well samples	Latitude (DMS)	Longitude (DMS)	Sodium (Na) in ppm
W1	15°24’05.5” N	74°00’18.6 E	8.3
W2	15°23’47.9” N	74°00’31.9” E	6.6
W3	15°23’37.9” N	74°00’10.6” E	15.1
W4	15°23’38.8” N	74°00’4.3” E	5.2
W5	15°24’29.4” N	74°01’12.7” E	5.4
W6	15°23’59” N	74°00’37” E	24.2
W7	15°23’6.5” N	73°59’59.8” E	4.7
W8	15°24’38.4” N	74°00’26.8” E	14.4
W9	15°24’6.2” N	74°00’37.2” E	14.4
W10	15°23’5.6” N	74°00’15.4” E	19.1
W11	15°23’54.3” N	74°00’3.5” E	17.6
W12	15°23’29.6” N	73°59’50.4” E	13.3
W13	15°24’19.5” N	74°00’31” E	8.9
W14	15°23’51.2” N	74°00’47.5” E	11.6
W15	15°23’55.8” N	74°00’43.8” E	13.4

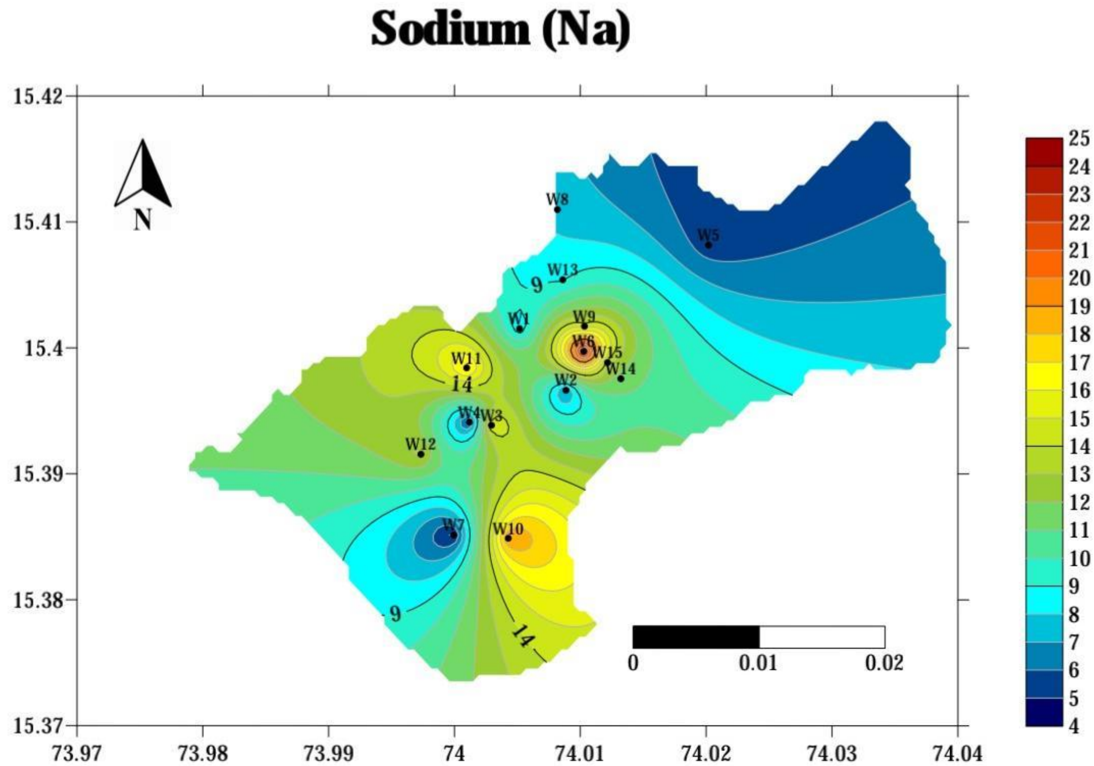

Figure 4.21: Contour distribution map showing Sodium concentration

Observation for Potassium (K)

The table 4.11 represents the potassium concentration in the study area. The variation in the Potassium concentration in the study area is shown in the figure 4.23. Water samples from W4, W5, W6, W8, W9, W11, W13, W14 and W15 were having Potassium content within the permissible limit as recommended by WHO (2017) whereas well samples W1, W2, W3, W7, W10 and W12 were exceeding the permissible limit of 12 mg/l. The highest K content was seen in W12 (147.4 ppm) and the lowest K content was observed in W15 (3.9 ppm). The average potassium in the study area is 22.78 ppm. High potassium in drinking water may lead to heart palpitations, shortness of breath, chest pain or vomiting.

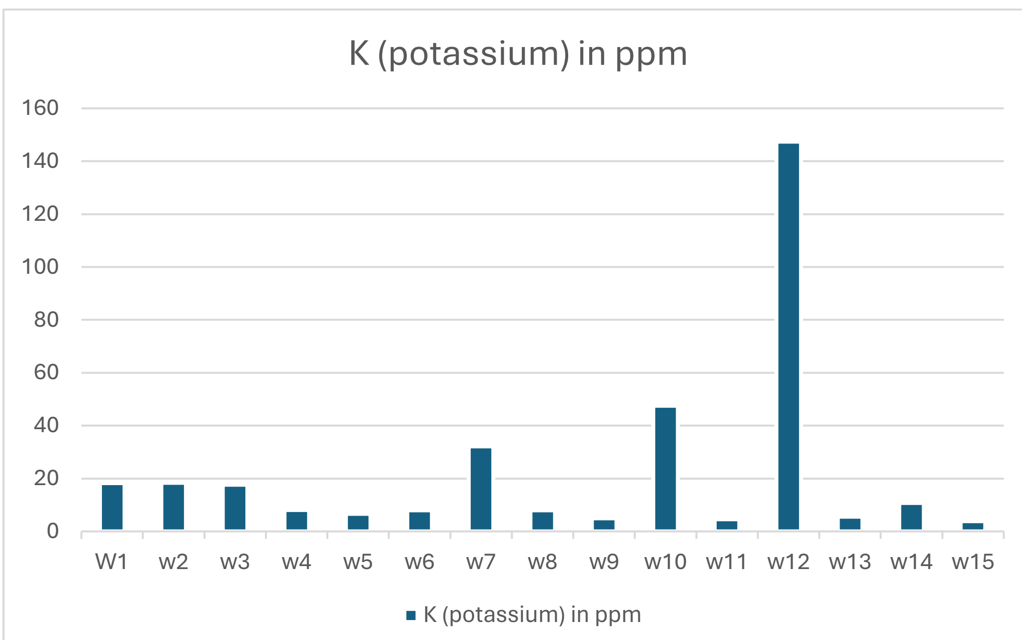

Fig 4.22: Variation of Potassium in study area.

Table 4.11: Potassium Concentration in Study Area

Well samples	Latitude (DMS)	Longitude (DMS)	Potassium (K) in ppm
W1	15°24’05.5” N	74°00’18.6 E	18.2
W2	15°23’47.9” N	74°00’31.9” E	18.4
W3	15°23’37.9” N	74°00’10.6” E	17.7
W4	15°23’38.8” N	74°00’4.3” E	8.1
W5	15°24’29.4” N	74°01’12.7” E	6.6
W6	15°23’59” N	74°00’37” E	8.0
W7	15°23’6.5” N	73°59’59.8” E	32.2
W8	15°24’38.4” N	74°00’26.8” E	8.0
W9	15°24’6.2” N	74°00’37.2” E	4.9
W10	15°23’5.6” N	74°00’15.4” E	47.5
W11	15°23’54.3” N	74°00’3.5” E	4.6
W12	15°23’29.6” N	73°59’50.4” E	147.4
W13	15°24’19.5” N	74°00’31” E	5.5
W14	15°23’51.2” N	74°00’47.5” E	10.7
W15	15°23’55.8” N	74°00’43.8” E	3.9

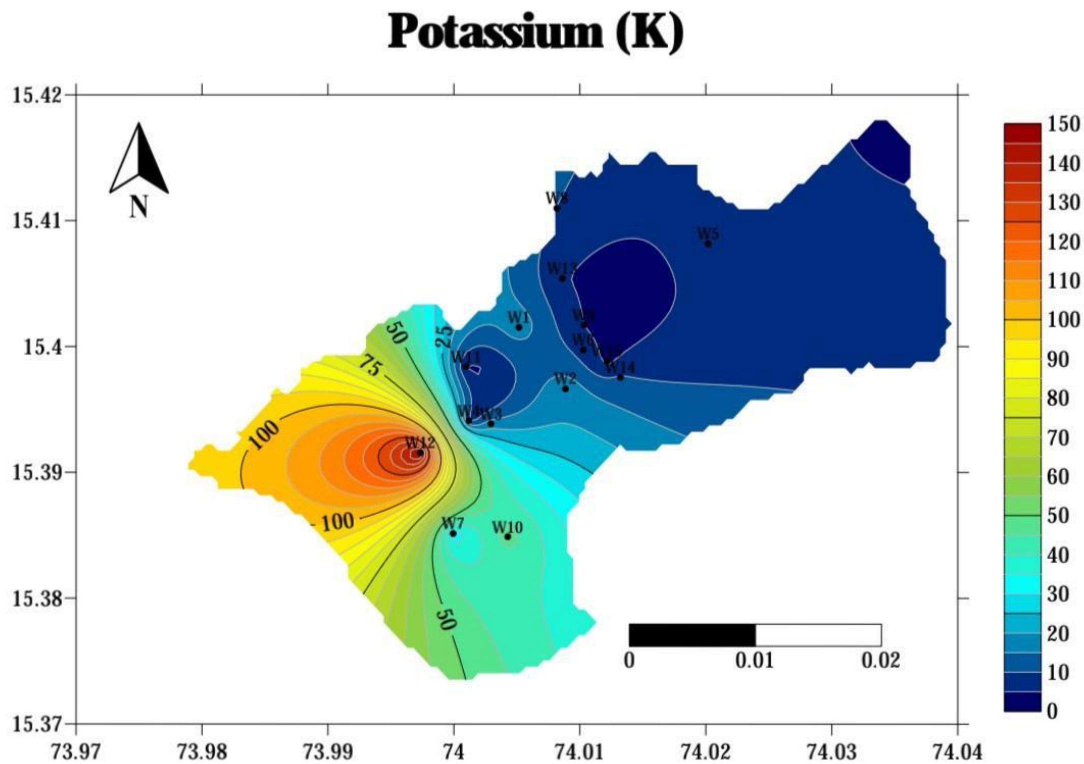

Figure 4.23: Contour distribution Map showing Potassium Concentration

Inference:

well samples W1, W2, W3, W7, W10 and W12 were exceeding the permissible limit of 12 mg/l. W12 lacks masonry buildup for the well structure. The use of potassium-containing fertilizers, such as potassium chloride (potash) or potassium sulfate, can increase potassium levels in groundwater through leaching from the soil into the aquifer. Irrigation practices can also contribute to the transport of dissolved potassium into groundwater. W10 is inside the wood mill and high Potassium can be due to decomposition of organic matter in the soil and subsurface layers can release potassium ions into groundwater.

4.2.3 Trace Element Analysis

A total of eleven samples were collected in 500 ml sterile polythene sample bottles. 10 drops of concentrated nitric acid (HNO3) were then added to the samples, which were then stored in a refrigerator to prevent the heavy metals from precipitating and to remain dissolved. After that, the samples were sent to the Central Coastal Agricultural Research Institute (ICAR), Old Goa, in 200ml sample bottles, for heavy metal analysis. Atomic Absorption Spectroscopy (AAS) was used to analyse the heavy metals. 4 heavy metals were analysed i.e. Iron (Fe), Manganese (Mn), Copper (Cu) and Zinc (Zn) and these parameters were used for determination of HPI and MI. The result obtained is shown in the table 4.12.

An ISO 9001:2008 Certified Institute

भाकृअनुप - केन्द्रीय तटीय कृषि अनुसंधान संस्थान

भारतीय कृषि अनुसंधान परिषद

ICAR- CENTRAL COASTAL AGRICULTURAL RESEARCH INSTITUTE

Indian Council of Agricultural Research

Ela, Old Goa 403 402 (INDIA)

F. No. ICAR-CCARI /NRM/SS/2023 **Date: 05/04/2024**

To,
Mahesh Mayekar,
Assistant Professor Goa University, Bambolim, Goa.

Name and address	: Mahesh Mayekar, Assistant Professor Goa University, Bambolim Goa.
Mobile Number	: 9158851415
Sample received on	: 23/02/2024
Sample described as	: Water
Parameters to be analyzed	: Mentioned in table below
Stamped by/Seal	: -
ID mark	: Mentioned in table
Laboratory where analyzed	: Soil Science Laboratory, Section, NRM ICAR-CCARI, Old Goa, 403402-Goa.

Test Report

No.	Sample ID	Parameter (Unit)			
		Iron (ppm)	Manganese (ppm)	Copper (ppm)	Zinc (ppm)
1	SC W-1	0.3057	ND	ND	0.0955
2	SC W-3	0.2701	ND	ND	0.1024
3	SC W-4	0.2076	ND	ND	0.0891
4	SC W-7	0.1247	ND	ND	0.1124
5	SC W-9	0.4617	ND	ND	0.0911
6	SC W-10	0.1481	0.7865	ND	0.0752
7	SC W-11	0.1163	ND	ND	0.0889
8	SC W-12	0.2430	ND	ND	0.1340
9	SC W-13	0.4265	ND	ND	0.1069
10	SC W-14	0.2332	ND	ND	0.0987
11	SC W -15	0.3301	ND	ND	0.092
12	SG W -1	1.1580	0.6096	ND	0.1449
13	SG W-2	0.2285	ND	ND	0.1043
14	SG W-3	0.0836	ND	ND	0.1670
15	SG W-5	0.1225	ND	ND	0.1759
16	SG W-7	0.1101	ND	ND	0.1772
17	SG W-8	0.7093	0.3925	ND	0.1328
18	SG W-10	0.3679	ND	ND	0.2282
19	SG W-11	0.2339	ND	ND	0.1545
20	SG W-12	2.1060	2.7910	ND	0.2007
21	SG W-13	0.2352	ND	ND	0.1821
22	SG W-14	0.2770	0.0902	ND	0.1547

Note: ppm – parts per million; ND- Non Detectable.

SAMPLE(S) NOT DRAWN BY ICAR-CCARI, OLD GOA, GOA

Dr. Gopal R. Mahajan
Sr. Scientist (Soil Science)

वरिष्ठ वैज्ञानिक (मृदा विज्ञान)
Senior Scientist (Soil Science)
विभाग - प्राकृतिक संसाधन प्रबंधन
Section - Natural Resource Management
ICAR – Central Coastal Agricultural Research Institute
Ela, Old Goa 403402, Goa, India

Note:

- Test results are related only to the sample(s) tested.
- The ICAR-CCARI is not responsible for the authenticity of the photocopied or computer scanned copy of this report.
- Samples will be retained by ICAR-CCARI for a period of 30 days after issue of the report, unless specific instructions to the contrary are received.
- No handwritten entries except signature and manual corrections are made in this report.

Disclaimer: The analysis report provided should not be used as a proof for any legal/commercialization / advertisement /certification related aspects.

Figure 4.24: ICAR report of heavy metals (SG samples are of this study area)

Table 4.12: Trace element Concentration in Study area

Well samples	Latitude (DMS)	Longitude (DMS)	Iron (Fe) in PPM	Manganese (Mn) in PPM	Copper (Cu) in PPM	Zinc (Zn) in PPM
W1	15°24’05.5” N	74°00’18.6 E	1.1580	0.6096	ND	0.1449
W2	15°23’47.9” N	74°00’31.9” E	0.2285	ND	ND	0.1043
W3	15°23’37.9” N	74°00’10.6” E	0.0836	ND	ND	0.1670
W5	15°24’29.4” N	74°01’12.7” E	0.1225	ND	ND	0.1759
W7	15°23’6.5” N	73°59’59.8” E	0.1101	ND	ND	0.1772
W8	15°24’38.4” N	74°00’26.8” E	0.7093	0.3925	ND	0.1328
W10	15°23’5.6” N	74°00’15.4” E	0.3679	ND	ND	0.2282
W11	15°23’54.3” N	74°00’3.5” E	0.2339	ND	ND	0.1545
W12	15°23’29.6” N	73°59’50.4” E	2.1060	2.7910	ND	0.2007
W13	15°24’19.5” N	74°00’31” E	0.2352	ND	ND	0.1821
W14	15°23’51.2” N	74°00’47.5” E	0.2770	0.0902	ND	0.1547

4.4.1 Iron (Fe)

Iron being the second most abundant metallic element on the Earth, has very small concentration in water. As rainwater infiltrates into the lithology and leaches the iron into the soil from where it enters the groundwater. Many industrial effluents released into the environment can contribute to addition of Iron in groundwater (Ngah S.A. and Nwankwoala H.O., 2013). As said by BIS in 2012, the acceptable limit is 0.3 mg/l. The Figure 4.24 shows the variation of Iron in the study area. The table 4.13 represents the Iron concentration in the study area.

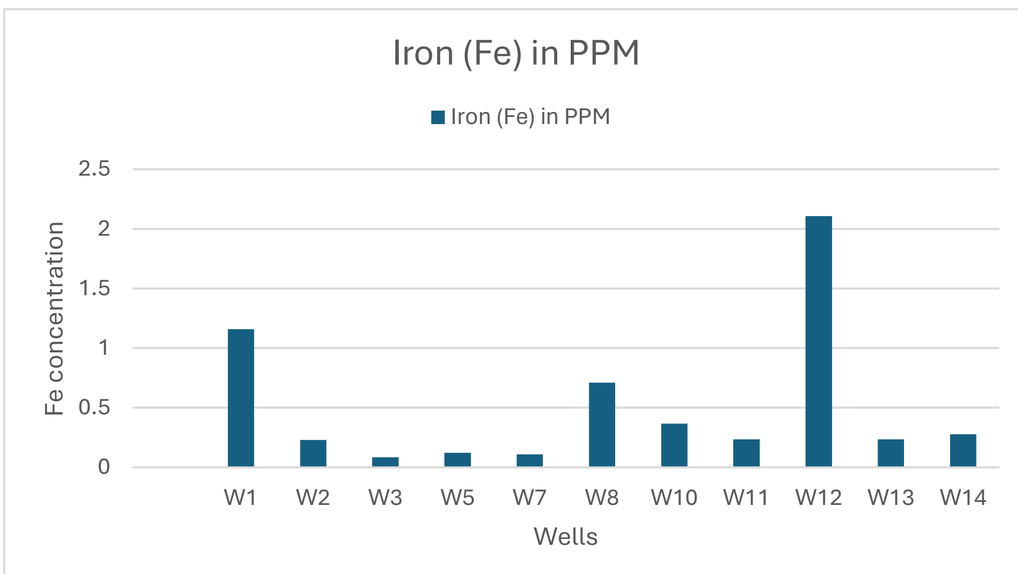

Figure 4.25: Variation in Iron Concentration in wells of study Area

Observation

The wells W2, W3, W5, W7, W11, W13 and W14 were within the acceptable limit of 0.3 mg/l and the well W1, W8, W10 and W12 are above the acceptable limit of 0.03 mg/l. The Iron concentration was in the range of 0.0836 mg/l (W3) to 2.1060 mg/l (W12). The average Iron concentration in the study area was 0.512 mg/l. During groundwater recharge events, such as heavy rainfall, water infiltrates through the soil and percolates into lateritic aquifer. This process can mobilize iron from the soil and rock layers, increasing iron concentrations in groundwater. High levels of Iron in drinking water can cause diabetes, stomach problems, nausea and even damage liver, pancreas and heart.

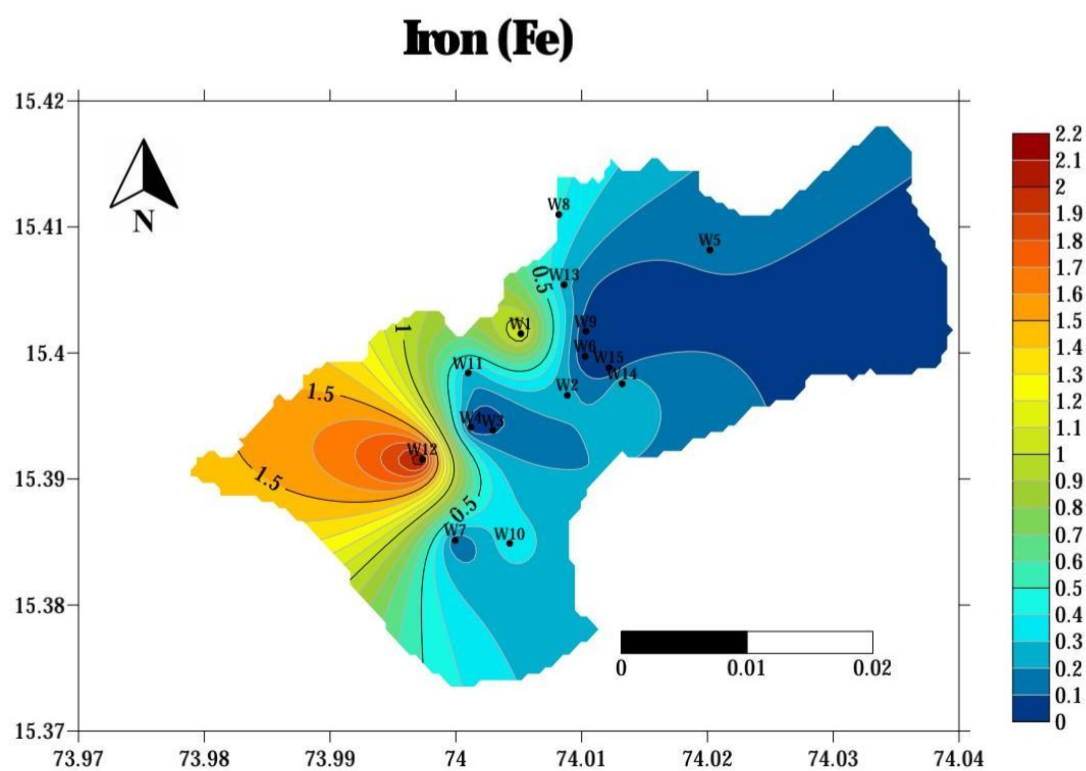

Figure 4.26: Contour distribution map showing Iron Concentration

Table 4.13: Iron Concentration in study area

Well samples	Latitude (DMS)	Longitude (DMS)	Iron (Fe) in PPM
W1	15°24’05.5” N	74°00’18.6 E	1.1580
W2	15°23’47.9” N	74°00’31.9” E	0.2285
W3	15°23’37.9” N	74°00’10.6” E	0.0836
W5	15°24’29.4” N	74°01’12.7” E	0.1225
W7	15°23’6.5” N	73°59’59.8” E	0.1101
W8	15°24’38.4” N	74°00’26.8” E	0.7093
W10	15°23’5.6” N	74°00’15.4” E	0.3679
W11	15°23’54.3” N	74°00’3.5” E	0.2339
W12	15°23’29.6” N	73°59’50.4” E	2.1060
W13	15°24’19.5” N	74°00’31” E	0.2352
W14	15°23’51.2” N	74°00’47.5” E	0.2770

4.4.2 Manganese (Mn)

According to BIS, 2012, the acceptable limit for Manganese is 0.1 mg/l and the maximum permissible limit is 0.3 mg/l. Manganese mostly occurs along with Iron (British Geological survey). The table 4.14 represents the Manganese concentration in the study area. The variation in manganese concentration is shown in the figure 4.27. Weathering of iron and manganese bearing rocks can be the source for Manganese in groundwater.

Observation

Manganese was analysed for 11 samples from Ponda city. Manganese was found only in 4 samples, and it was not detected in rest of the samples. 8 wells were within the acceptable limit of Manganese as said by BIS 2012. 3 wells were above the acceptable limit of 0.3 mg/l. The Manganese content was found in the range of 0.0902 mg/l to 2.791 mg/l. High levels of Manganese in groundwater can cause problem with memory and attention.

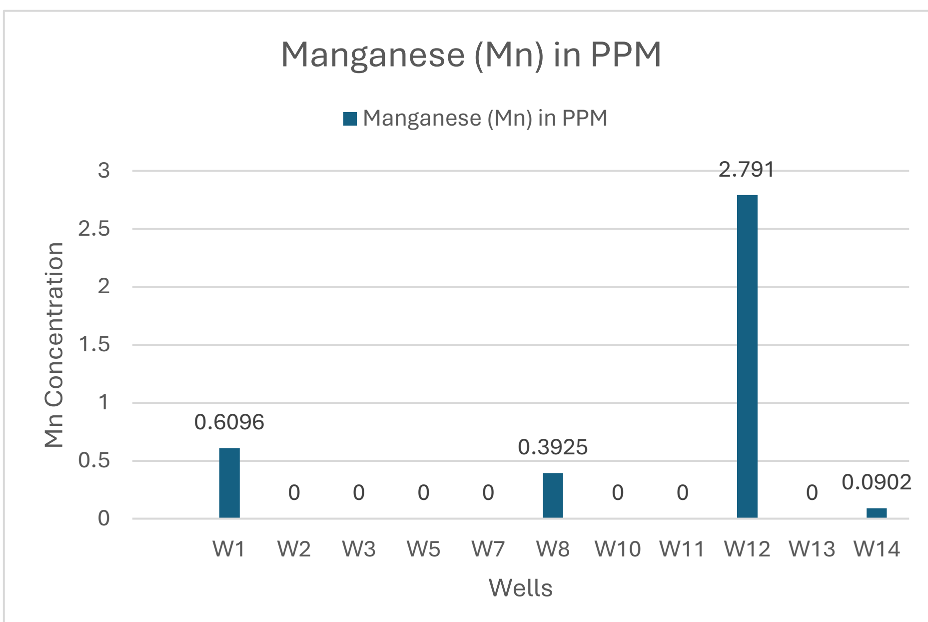

Figure 4.27: Variation Of Manganese Concentration in wells of study area

Table 4.14: Manganese Concentration in the study area

Well samples	Latitude (DMS)	Longitude (DMS)	Manganese (Mn) in PPM
W1	15°24’05.5” N	74°00’18.6 E	0.6096
W2	15°23’47.9” N	74°00’31.9” E	ND
W3	15°23’37.9” N	74°00’10.6” E	ND
W5	15°24’29.4” N	74°01’12.7” E	ND
W7	15°23’6.5” N	73°59’59.8” E	ND
W8	15°24’38.4” N	74°00’26.8” E	0.3925
W10	15°23’5.6” N	74°00’15.4” E	ND
W11	15°23’54.3” N	74°00’3.5” E	ND
W12	15°23’29.6” N	73°59’50.4” E	2.7910
W13	15°24’19.5” N	74°00’31” E	ND
W14	15°23’51.2” N	74°00’47.5” E	0.0902

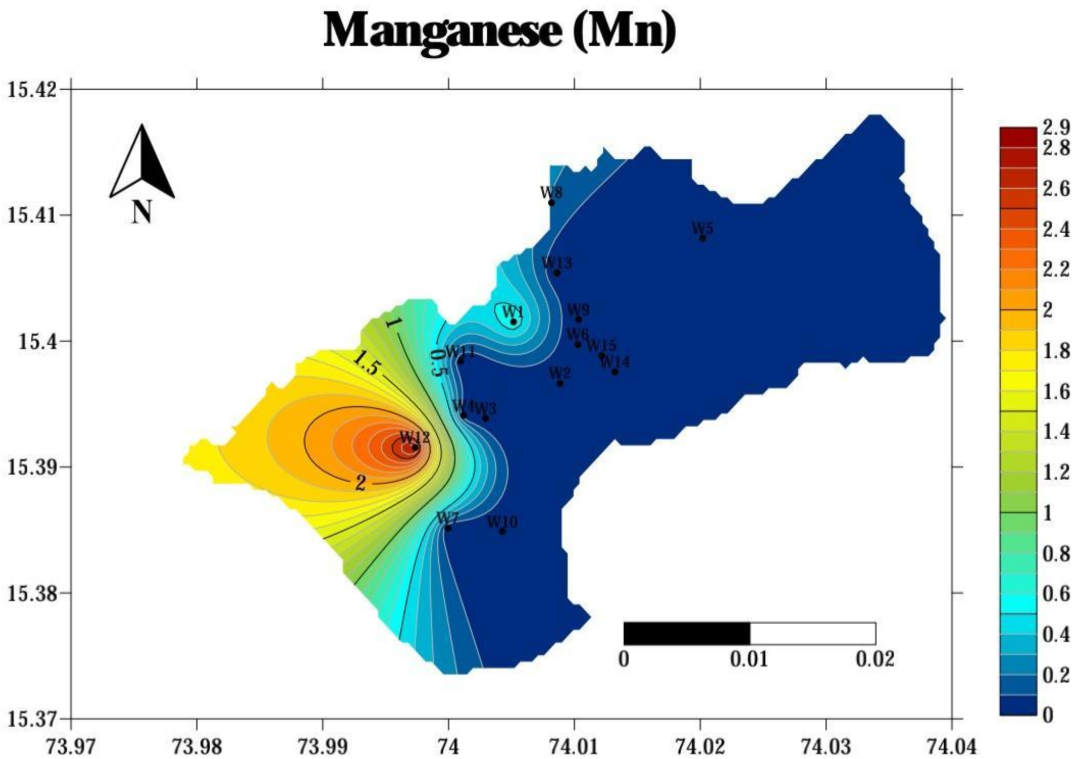

Figure 4.28: Contour distribution map showing Manganese

4.4.3 Copper

According to BIS 2012, the acceptable limit for copper is 0.05 mg/l and the maximum permissible limit is 1.5. The main source of copper is mining operation along with incineration. Weathering of soil or industrial discharge may be the reason for high copper.

Observation

None of the well samples had copper content detected. All the samples were significantly below the acceptable limit of 0.05 mg/l, as advised by BIS 2012. High copper in drinking water can lead to liver damage, headache, vomiting, diarrhea and kidney disease.

4.4.4 Zinc (Zn)

The acceptable limit for Zinc (Zn) is 5 mg/l and the maximum permissible limit for zinc (Zn) is 15 mg/l as stated by BIS 2012. High levels of zinc in drinking turns the water into milky or chalk like appearances and the taste changes to metal like taste (S.S.Negus et al., 1938). The table 4.15 represents the Zinc concentration the study area. The variation in Zinc concentration is shown in the figure 4.29. Industries such as metal plating, galvanizing, and battery manufacturing may discharge zinc-containing effluents into surface water bodies or soil, which can infiltrate into groundwater.

Observation

All the wells were below the acceptable limit of 5 mg/l as recommended by BIS 2012. The average Zinc concentration in the study area is 0.166 mg/l. The highest zinc concentration was found in W10 (0.2282 mg/l) and the lowest was found in W2 (0.1043 mg/l). High Zinc in Drinking water can lead to stomach cramps, nausea and vomiting.

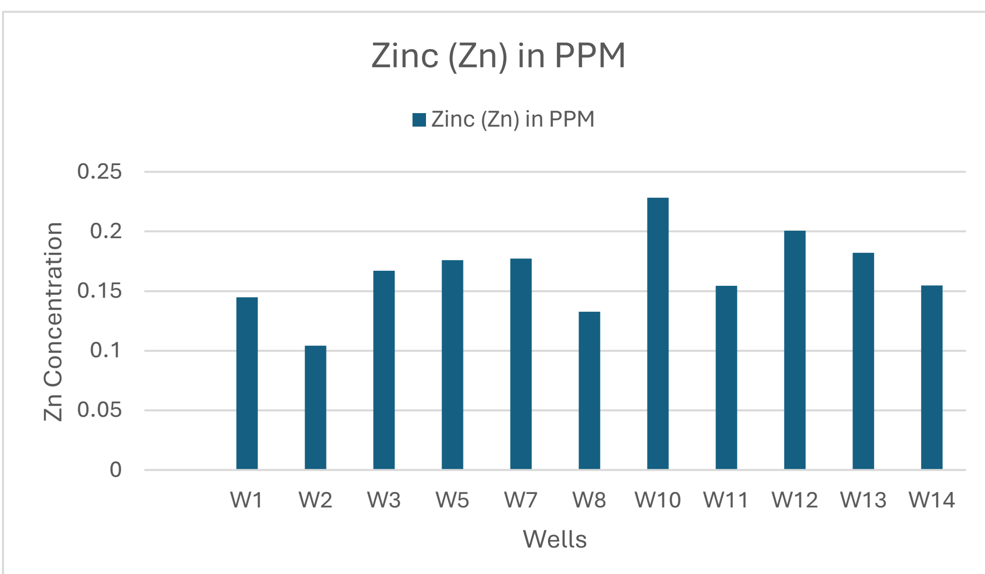

Figure 4.29: Variation of Zinc Concentration in wells of study area

Table 4.15: Zinc Concentration in the study area

Well samples	Latitude (DMS)	Longitude (DMS)	Zinc (Zn) in PPM
W1	15°24’05.5” N	74°00’18.6 E	0.1449
W2	15°23’47.9” N	74°00’31.9” E	0.1043
W3	15°23’37.9” N	74°00’10.6” E	0.1670
W5	15°24’29.4” N	74°01’12.7” E	0.1759
W7	15°23’6.5” N	73°59’59.8” E	0.1772
W8	15°24’38.4” N	74°00’26.8” E	0.1328
W10	15°23’5.6” N	74°00’15.4” E	0.2282
W11	15°23’54.3” N	74°00’3.5” E	0.1545
W12	15°23’29.6” N	73°59’50.4” E	0.2007
W13	15°24’19.5” N	74°00’31” E	0.1821
W14	15°23’51.2” N	74°00’47.5” E	0.1547

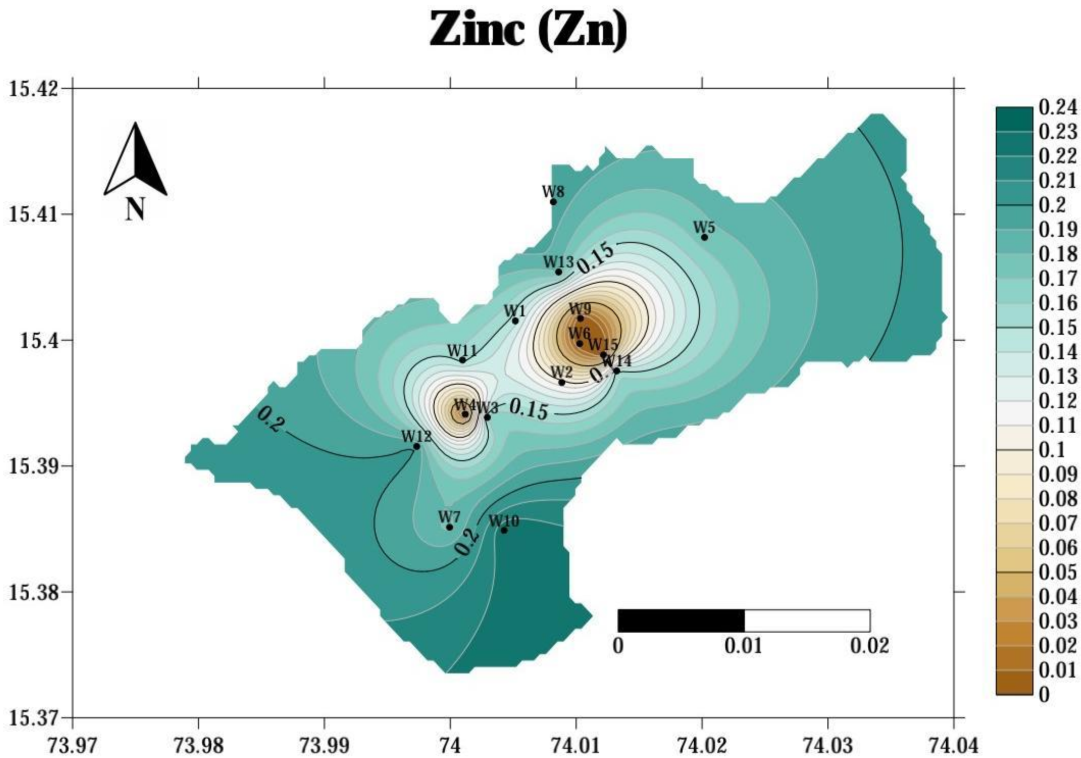

Figure 4.30: Contour Distribution map showing zinc Concentration

4.3 HEALTH RISK ASSESSMENT

Health Risk assessment was done in Ponda city by using indices like Heavy Metal Pollution Index (HPI), Metal Index (MI), and Water Quality Index (WQI). 15 well samples were collected for the determination of WQI and 11 samples were used for calculating HPI and MI.

4.3.1 Heavy Metal Pollution Index

A rating that represents the combined impact of dissolved heavy metals is known as the Heavy Metal Pollution Index, or HPI. The HPI is determined by considering whether groundwater is suitable for human consumption in terms of metal contamination. 4 heavy metals were taken into consideration while determining the HPI which are Iron, Manganese, Copper and Zinc. The classification given by Vetrimurugan et al., 2013 is shown in table 4.16. The table 4.17 shows the HPI in the Study area. The figure 4.30 shows the variation in HPI in the study area.

Table 4.16: Classification of Heavy Metal Pollution Index (Vetrimurugan et al., 2013).

HPI values	Characteristics of water quality
0-25	Excellent
26- 50	Good
51-75	Poor
76-100	Very poor
HPI<100	Unfit for consumption

The highest HPI is observed in well 12 (937.20) and the lowest HPI is found in well 14 (4.96). The wells W1, W8, W12 are having HPI more than 100 so it is unfit for consumption. The Wells W2, W3, W5, W7, W10, W11 and W13 are having good quality water. The well W14 has excellent water quality and is best suitable for drinking.

Table 4.17: HPI in the study area

Wells	HPI Values	characteristics
W1	192.916	Unfit for consumption
W2	36.009	Good
W3	40.086	Good
W5	38.988	Good
W7	39.337	Good
W8	108.852	Unfit for consumption
W10	35.891	Good
W11	35.850	Good
W12	937.204	Unfit for consumption
W13	35.810	Good
W14	4.963	Excellent

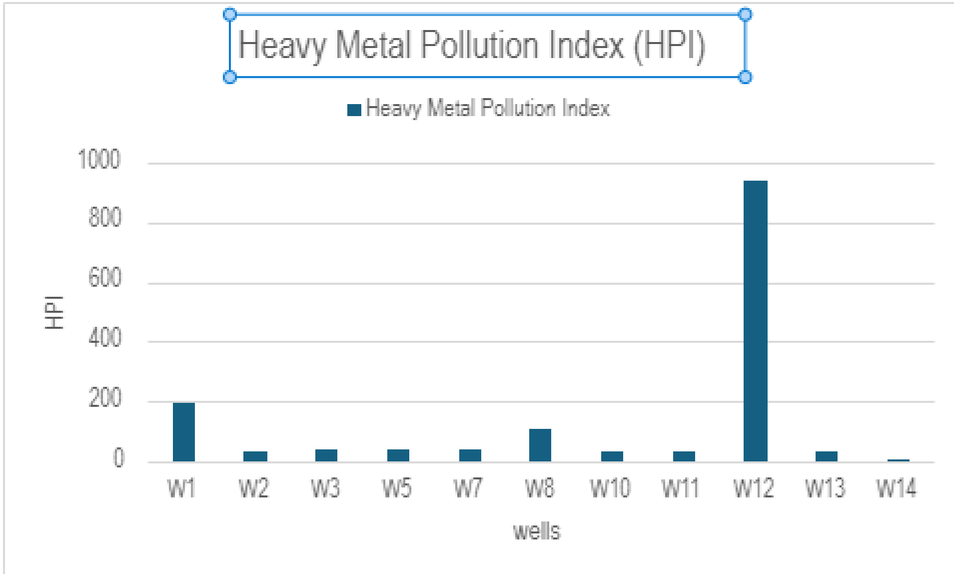

Figure 4.31: Variation in Heavy Metal Pollution Index

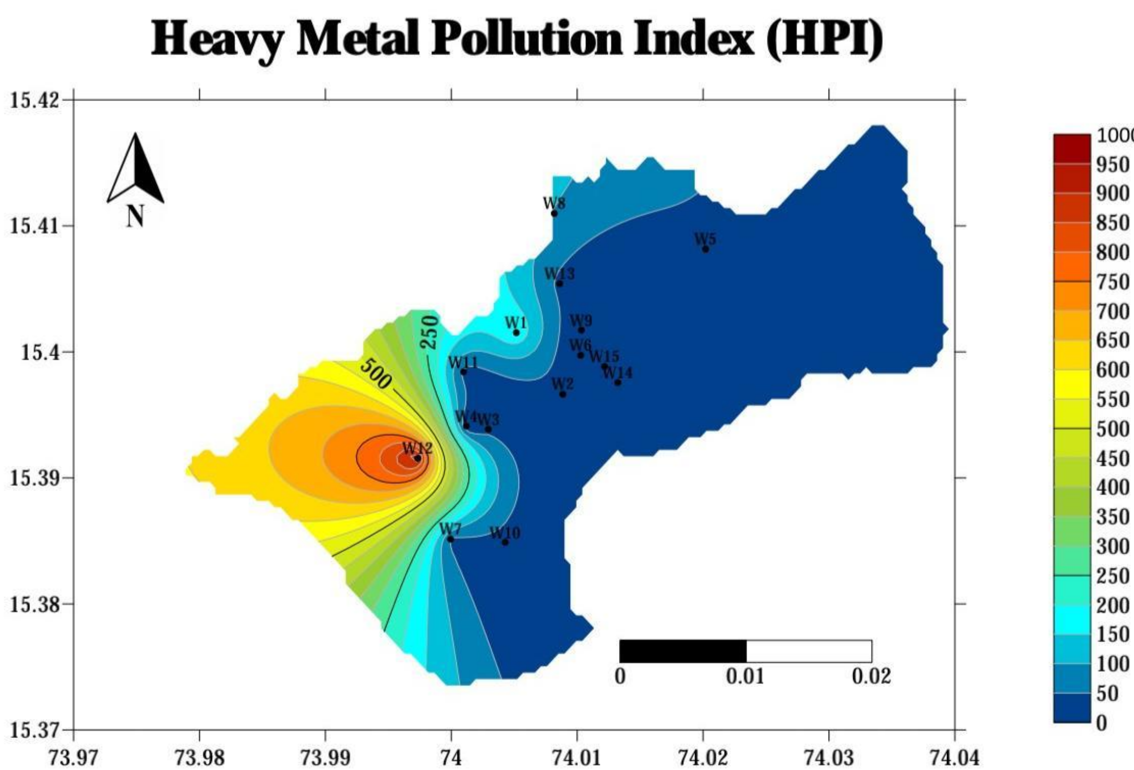

Figure 4.32: Contour Distribution map showing Heavy metal Pollution Index

4.3.2 Metal Index (MI)

Caerio et al. (2005) created this indexing technique to quickly evaluate the quality of water and forecast the possible cumulative effect of harmful elements. Four heavy metals were taken into consideration while determining the HPI which are Iron, Manganese, Copper and Zinc. The Metal index classification according to Caerio et al., 2005 is shown in the table 4.18. The table 4.19 represents Metal Index in the study area. The variation in Metal Index is shown in figure 4.31.

Table 4.18: Metal Index Classification (Source: Caerio et al., 2005).

class	Property /characteristics	MI values
I	Very Pure	< 0.3
II	Pure	0.3 - 1
III	Slightly Affected	1 - 2
IV	Moderately Affected	2- 4
V	Strongly Affected	4 - 6
VI	Seriously Affected	> 6

The Highest metal index is seen in W12 (11.423) and the lowest Metal index is seen in W3 (0.095). The W12 has high iron content as well as high manganese concentrations which were above the maximum permissible limit. W2, W3, W5, W7, W11 and W13 has MI values less than 0.3 which means the water is not contaminated by heavy metals. W10 and W14 were having MI values less than 1 but more than 0.3 which means there might be potential contamination but till now the water quality is pure with respect to heavy metal contamination. W8 was having MI value 2.026 and W1 was having MI value 3.2 which shows that the water is moderately affected by heavy metal concentration. W12 is having high MI value i.e. 11.423 which means that the water is seriously affected by the heavy metal contamination.

Table 4.19: Metal Index in the study area

Wells	Metal Index Values	Property/characteristics	Class
W1	3.200	Moderately affected	iv
W2	0.236	Very Pure	i
W3	0.095	Very Pure	i
W5	0.134	Very Pure	i
W7	0.122	Very Pure	i
W8	2.027	Moderately affected	iv
W10	0.383	Pure	ii
W11	0.244	Very Pure	i
W12	11.423	Seriously affected	vi
W13	0.247	Very Pure	i
W14	0.588	Pure	ii

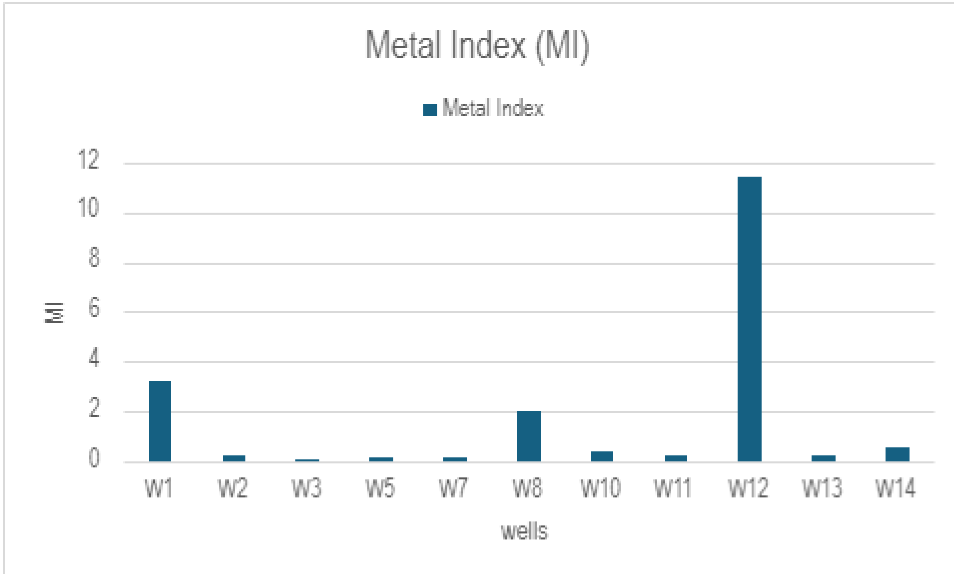

Figure 4.33: Variation in Metal index in the study area

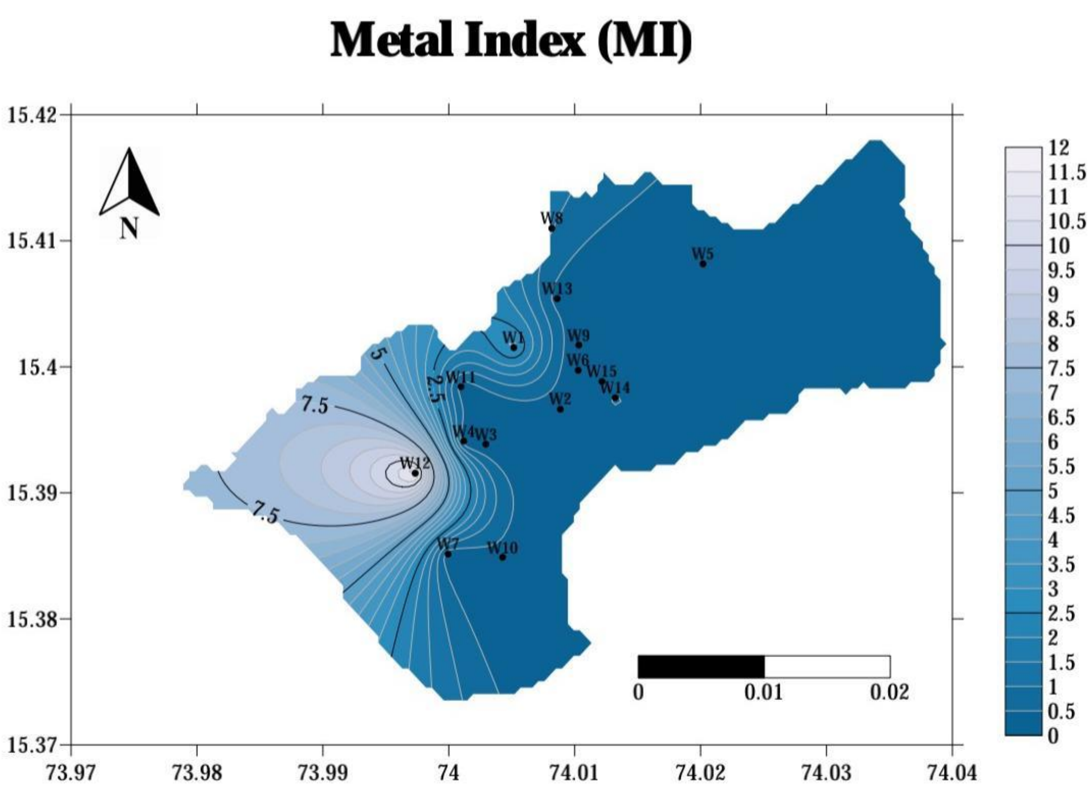

Figure 4.34: Contour Distribution map showing Metal Index

4.3.3 Water Quality Index

Based on a number of water quality parameters, a water quality index gives a single figure that represents the overall water quality at a specific place and time. An index's purpose is to translate complicated data about water quality into information that the general public can use and understand. WQI is among the best instruments for characterizing the condition of the water and assessing its suitability for various applications. WQI helps environmental agencies modify their environmental policies by using data on water quality. 8 parameters i.e. pH, EC, TDS, Calcium, Magnesium, Sodium, Potassium and Total hardness was taken into consideration during determination of Water Quality Index. The classification for Water Quality index is displayed in table 4.20. The water quality Index in the study area is shown in table 4.21.

Table 4.20: Water quality index classification (Source: Rajesh Prajapati and Ram Bilas., 2018)

Water Quality index	Status of water Quality
0 - 25	Excellent
26 - 50	Good
51 – 75	Poor
76 - 100	Very poor
> 100	Unfit for drinking

Table 4.21: Water Quality Index in the study area

Well samples	Latitude (DMS)	Longitude (DMS)	Water Quality Index (WQI)	Water Quality Status
W1	15°24’05.5” N	74°00’18.6 E	90.881	Very Poor
W2	15°23’47.9” N	74°00’31.9” E	80.036	Very Poor
W3	15°23’37.9” N	74°00’10.6” E	85.153	very Poor
W4	15°23’38.8” N	74°00’4.3” E	53.634	Poor
W5	15°24’29.4” N	74°01’12.7” E	51.555	Poor
W6	15°23’59” N	74°00’37” E	61.313	Poor
W7	15°23’6.5” N	73°59’59.8” E	141.727	Unfit For Consumption
W8	15°24’38.4” N	74°00’26.8” E	65.336	Poor
W9	15°24’6.2” N	74°00’37.2” E	56.806	Poor
W10	15°23’5.6” N	74°00’15.4” E	178.32	Unfit For Consumption
W11	15°23’54.3” N	74°00’3.5” E	60.746	Poor
W12	15°23’29.6” N	73°59’50.4” E	413.31	Unfit For Consumption
W13	15°24’19.5” N	74°00’31” E	42.086	Good
W14	15°23’51.2” N	74°00’47.5” E	51.821	Poor
W15	15°23’55.8” N	74°00’43.8” E	61.421	Poor

Observations

The W7, W10 and W12 has water quality index more than 100, hence it is unfit for drinking purpose. W13 was the only well having good water quality. 3 wells, W1, W2 and W3 were having water quality index in the range 76-100 hence it has very poor-quality water. The remaining 8 wells have poor quality water as the water quality index for these wells is 51-75. The water having WQI less than 100 can be consumed. So only 3 wells have water that is unsuitable for drinking.

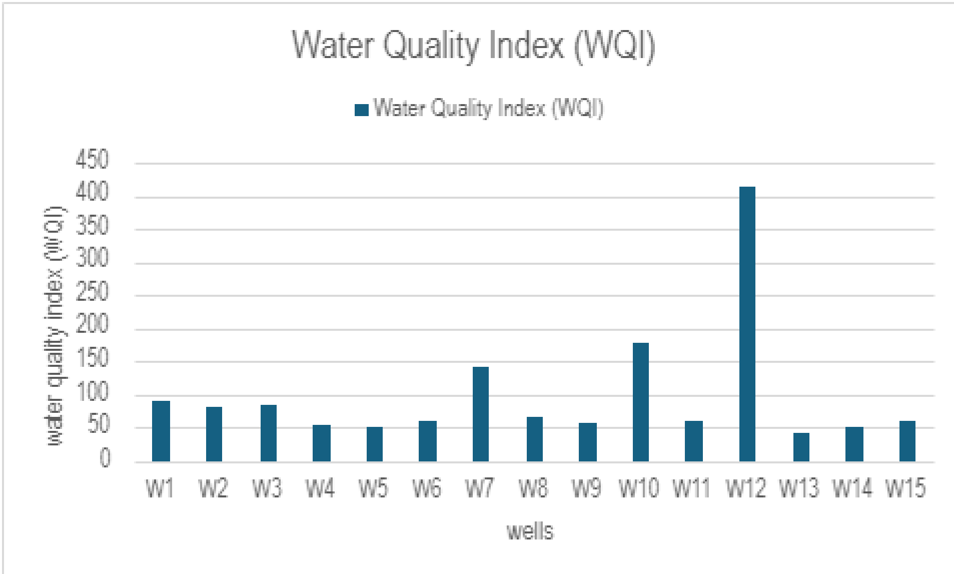

Figure 4.35: Variation in Water Quality index (WQI) in the study area

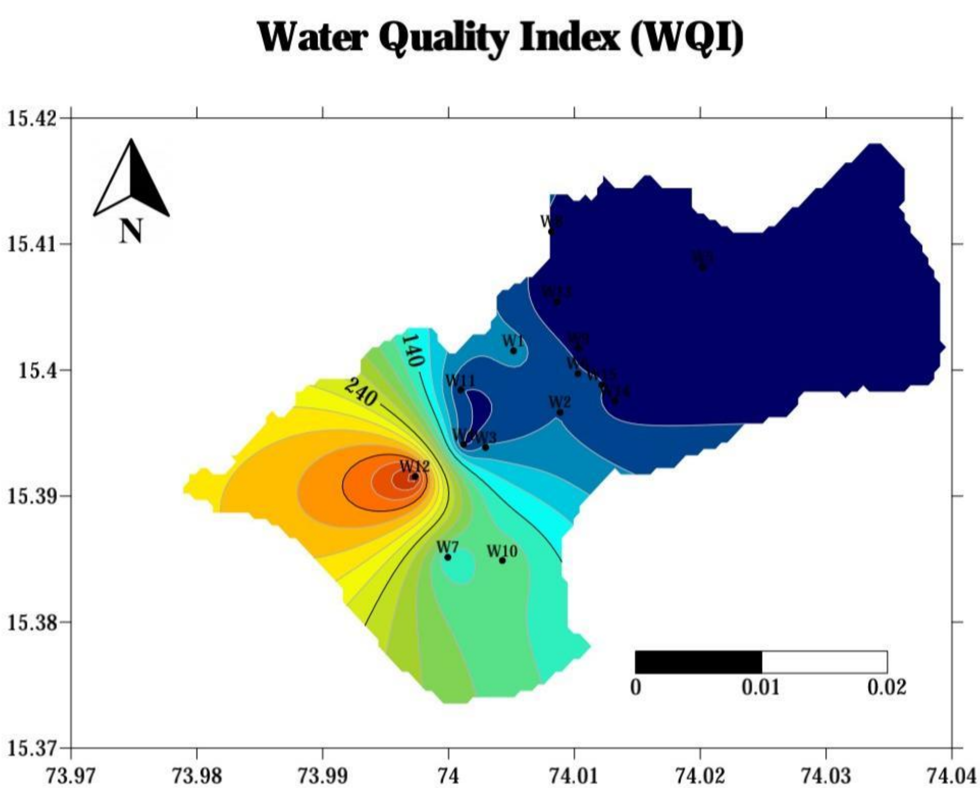

Figure 4.36: Contour Variation map showing Water Quality Index (WQI)

4.4 CONCLUSIONS

1) It was observed that the shallow aquifer in the study area is laterite.

2) The average pH in the study area during post monsoon was 6.056. 12 samples out of 15 had pH below the permissible limit given by BIS (2012) which is 6.5 to 8.5. Dry deposition of pollutants such as sulphur dioxide and nitrogen oxides from industrial activities and vehicular emissions may accumulate on the land surface during the monsoon season and be washed into water bodies during the post-monsoon period, contributing to a decrease in pH levels.

3) The average EC value during post monsoon was 232.53 uS/cm. Only 2 wells W5 and W8 exceeded the permissible limit of 400 uS/cm given by WHO (2007). Plantation of different vegetables and fruits were there in vicinity of W5, the use of fertilizers, particularly those containing soluble salts like potassium nitrate or ammonium sulphate can increase EC levels in groundwater through leaching from the soil into the aquifer. W8 was contaminated with plastic bottles and other waste products which can decay in well and increase the EC.

4)The average TDS value during post monsoon was 148.82 ppm. Only one well i.e. W8 had TDS value higher than the acceptable limit of 500 mg/l as recommended by BIS 2012.

5) All the wells have total hardness within the acceptable limit of 200 mg/l as recommended by BIS (2012). According to USGS classification (2018), 1 well was having soft water, 11 wells were having moderately hard water and 3 wells were having hard water.

6) All wells were having Calcium concentration within the acceptable limit of 75mg/l as recommended by BIS (2012). The average Ca hardness in the study area was 12.59 mg/l.

7) All Wells were having Magnesium concentration within the permissible limit of 100 mg/l as recommended by BIS (2012). Only one sample was having Mg concentration higher than the acceptable limit of 30 mg/l according to BIS 2012.

8) All Wells were having Sodium Concentration within the permissible limit of 200 mg/l as recommended by WHO (2017). The Average Sodium content in the study area was 12.15 mg/l.

9) Six wells were above the permissible limit of 12 mg/l for Potassium according to WHO (2017). The average Potassium content in the study area was 22.78 mg/l. W12 lacks masonry buildup for the well structure. The use of potassium-containing fertilizers, such as potassium chloride (potash) or potassium sulfate, can increase potassium levels in groundwater through leaching from the soil into the aquifer. Irrigation practices can also contribute to the transport of dissolved potassium into groundwater. W10 is inside the wood mill and high Potassium can be due to decomposition of organic matter in the soil and subsurface layers can release potassium ions into groundwater.

10) Iron concentration for 7 wells were within the acceptable limit of 0.3 mg/l. Three wells were exceeding the acceptable limit of 0.3 mg/l according to BIS (2012). The average Iron concentration in the study area was 0.512 mg/l. During groundwater recharge events, such as heavy rainfall, water infiltrates through the soil and percolates into lateritic aquifer. This process can mobilize iron from the soil and rock layers, increasing iron concentrations in groundwater.

11) Manganese was detected in just 4 wells, of which 3 had manganese concentrations exceeding the maximum permissible limit of 0.3 mg/l with regards to BIS (2012). Weathering of iron and manganese bearing rocks can be the source for Manganese in groundwater.

12) No traces of copper were found in the wells within the study area.

13) Zinc concentration was below the acceptable limit of 5 mg/l with regards to BIS (2012). The average Zinc concentration in the study area was 0.166 mg/l.

14) The groundwater is moving from the South Eastern region to the North Western region, and eventually it will empty into the river Zuari.

15) Three wells had HPI more than 100 so it is unfit for consumption. The well W14 has excellent water quality and is best suitable for drinking. Remaining wells had good water quality.

16) Six wells had very pure water according to the Metal index. One well was seriously affected and Two wells were moderately affected. Two wells had pure water.

17) Three wells had water quality index more than 100, hence it is unfit for drinking purpose. W13 is the only well which had good water quality. 3 wells had very poor-quality water. The remaining 8 wells had poor quality water.

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