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Assessment and spatial distribution of groundwater quality in Bidadi industrial area, Ramanagara district, Karnataka using water quality index (WQI) and GIS

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Abstract
Over time, there has been a rise in water consumption, which has caused water shortages throughout the world. The problem of water pollution makes the situation much worse. India is experiencing a freshwater crisis, partly as a result of poor water management practises and pollution, which restrict access to reliable water sources. States around the nation are seriously at risk from industrial pollution. The dangers posed by industrial waste are significant in several states across the nation. Ground water samples from 46 sources, were collected from Bidadi Industrial for the physico-chemical assessment and were analyzed as per BIS:10500-2015 standards for physical and chemical parameters. Parameters such as the pH, Hardness, Potassium, Calcium and Sodium were found to be breaching the drinking water standards but the over all WQI of Bidadi Industrial area is Good (50.75).

Keywords: Water shortages, industrial pollution, hardness, potassium, calcium, water pollution

Introduction
Water is a basic requirement for the functioning of all life forms on earth. It is a well-known fact that presence of water makes Earth the only inhabitable planet. However, despite its vast quantity, water is very much limited. Additionally, while water is plentiful, it should be noted that not all of it is safe to consume. Groundwater is an essential source of water for humanity. Though it is beneath the Earth's surface, groundwater contributes significantly to the water cycle and accounts for 99% of the planet's liquid fresh water. The groundwater reservoir that feeds rivers, lakes, and wetlands when they are in need of water and removes some of their flow when there is a plenty of surface water present are all surface expressions of groundwater. Mining is one example of a human activity that has altered the natural, physical, and biological redistribution of heavy metals. These modifications have caused these metals to bio-accumulate in plants, animals, and finally in the human body. As a result, heavy metal-related pollution has negatively impacted human health [1]. The presence of heavy metals (Cd, As, Ni, and Hg) in groundwater at levels beyond the allowable limits can harm ecosystems, plants, and animals, as well as pose substantial health risks to people [2]. India, like many other countries, is experiencing a fresh water crisis, which is mostly caused by poor water management practises and environmental degradation, which restrict access to reliable water sources. Groundwater and surface water quality have both declined as a result of the fast rise of industrialisation and urbanisation [3]. Due to industrial waste, many states in the nation are in grave danger. Humans face a serious challenge with water quality because it directly affects their health [4].

To guarantee its ideal and long-term safe use, the groundwater quality study is necessary. There are many water quality principles depending on the type of water use. WQI is an effective method for evaluating the appropriateness and quality of drinking water in any setting. In addition, using the compositional and spatial characteristics of land cover, Multiple Linear Regression (MLR) models were used to predict the degree of water quality parameters. According to the awareness examination model, it was possible to plan borders that indicate substantially poorer water quality and significant spatial inconsistency. Rapid industrialization and urbanisation will contaminate groundwater either directly or indirectly. This study's primary goal is to determine the standards of groundwater for drinking purposes using Geographic Information System (GIS) and Remote Sensing (RS) approaches in combination with water quality indexing related to significant physio-chemical constraints of the groundwater from Bidadi Industrial Area.

Study Area

Fig 1: Location of Study Area (Bidadi)

Bidadi Industrial area is located in the north-eastern part of Ramanagara Taluk, Ramanagara district, Karnataka. It is located at N12º47' and E77º23', Industrial area covers 852 acres with average 748 m elevation (2454 feet) average high of 28 °C and an average low of 20.1 °C. Sampling sites and study areas are presented in the rainy season temperature varies between 28 °C and 20.1 °C. There are 181 rainfall days, throughout the year and 773 mm of precipitation is received. According to the 2011 census, total population is approximately 3.5 lakhs. A detailed survey was conducted to identify the number of existing bore wells. The survey was conducted by visiting each industrial plot and surrounding the industries by identifying the existing bore wells.

Materials and Methods

Sample collection and analysis

The investigation of quality of ground water of Bidadi Industrial Area of Ramnagara district was undertaken in 2022. Sample Location names along with GPS data is shown in the following Table

Water samples from the study area were collected for the physico-chemical analysis. Water sample locations were recorded using a GPS device. One-liter polythene cans were used to collect water samples, which were subsequently taken to the lab for physico-chemical examination. Then, they were examined for physical and chemical characteristics such as pH, electrical conductivity, total hardness, TDS, calcium, magnesium, sodium, potassium, iron, carbonates, sulphates, bicarbonates, nitrate, chloride, fluorides, etc. in accordance with BIS:10500-2015 requirements. Creating a spatial distribution map and calculating the WQI for each physicochemical parameter

Table 1: Sample Location data

SL No.	Latitude	Longitude
1	12.82113	77.4124
2	12.82192	77.41283
3	12.8087	77.42248
4	12.80954	77.41824
5	12.78316	77.41998
6	12.78542	77.41287
7	12.77908	77.41543
8	2.778645	77.422484
9	12.80556	77.42046
10	12.79867	77.4218
11	12.79465	77.42313
12	12.79172	77.42747
13	12.78235	77.42532
14	2.773841	77.411344
15	12.77834	77.41964
16	12.77161	77.41694
17	12.79753	77.42897
18	12.81426	77.42505
19	12.81056	77.42505
20	12.80072	77.41927
21	12.79176	77.42514
22	12.79176	77.42512
23	12.78285	77.43086
24	12.78314	77.40961
25	12.78148	77.40709
26	12.78209	77.4058
27	12.76694	77.41563
28	12.76943	77.41649

Calculation of water quality index

Horton developed the WQI (Water Quality Index) [5] in the United States by selecting the 10 most commonly used water quality variables like pH, dissolved oxygen (DO), coliforms, chloride and chloride alkalinity etc. and has been widely accepted and used in European, African and Asian countries. WQI has been estimated in three steps utilizing weighed arithmetic index approaches [14].

Parameter Selection: This is done at the discretion of professional experts, agencies or government institutions that is determined in the legislative area. It is recommended to select variables from five classes that have a large impact on water quality: oxygen content, eutrophication, health aspects, physical properties, and dissolved matter.

Determination of Quality Function (curve) for Each Parameter Considered as the Sub - Index: Sub - indices are converted to non - dimensional scalar values from the variables of different units (ppm, saturation percentage, counts / volume etc.)

Sub - Indices Aggregation with Mathematical Expression: Mathematical or geometric averages are frequently used to express this. Numerous indicators of water quality, including The National Sanitation Foundation Water Quality Index (NSFWQI), the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), the Oregon Water Quality Index (OWQI), and other national and international organisations have developed the Weight Arithmetic Water Quality Index (WAWQI), for example. These WQI have been used to assess the quality of the water in a particular area.

Additionally, these indices frequently base their calculations on different numbers and kinds of water quality measures in comparison to the corresponding requirements of a certain area. Water quality indicators are recognised for their capacity to precisely and promptly reflect annual cycles, regional and temporal variations in water quality, and fluctuations in water quality even at low concentrations. The available indices include several variances and restrictions based on the quantity of water, according to the examined literature.

It may be more appropriate to summarise the state of water quality across a variety of water types using the water quality index rather than a single parameter because it indicates the degree to which a number of water quality parameters vary from normal, expected, or "ideal" concentrations [7]. The Water Quality Index is an effective way to understand the properties of water. It then becomes an important parameter for groundwater quality assessment and management. WQIs are calculated taking into account the suitability of surface water and/or groundwater for human consumption. WQI is determined as a weighted index representing the combined influence of various chemical parameters. WQI strives to find out if groundwater is suitable for human use. Therefore, 15 parameters are required to calculate the WQI in this study pH, conductivity, total dissolved solids, total hardness, alkalinity, calcium, magnesium, sodium, potassium, chloride, sulfate, nitrate, fluoride, and iron were considered.

Table 2: Methods/Instruments

Parameter	Method / instrument
pH	Digital pH meter
Alkalinity	Titrimetry
Electrical conductivity (EC)	Digital conductivity meter
Total Dissolved Solids (TDS)	Indirect method 0.64x ECµZ l cm
Calcium Hardness and Total hardness (TH)	EDTA-Titrimetry
Magnesium hardness (MgH)	Indirect method (TH - (2.5x CaH)!4.1
Sodium (Na) & Potassium (K)	Flame photometer
Iron (Fe)	1,10 phenanthro line-Spectrophotometry
Bicarbonates (HC03) + carbonates (C03)	Indirect method 1.31x Alkalinity
Chlorides (Cl)	Mobr's-Titrilnetry
Sulphates (S04)	Spectrophotometry
Phosphates (P04)	Ammonium molybdate method-Spectrophotometry
Fluorides (F)	Selective ion meter

Methodology for Calculating WQI

Collection of data of various physico -chemical water quality parameters. Proportionality constant-K value using formula

$$K = (1/(1/\sum_i^n = 1\ si))$$

Where —si is standard permissible for n^{th} parameter.

Calculated quality rating for n^{th} parameter (q n) where there are n parameters. This is

$$Q_n = 100*((V_N - V_{io})/(S_n - V_{io}))$$

Whereas

$V_n =$ Estimated value of the nth parameter of the given sampling station.

V_{io} = Ideal value of n^{th} parameter in pure water.

S_n = Standard permissible value of the nth parameter.

Calculate unit weight for the n^{th} parameter W_n =(K/S_n)

Calculate Water Quality Index (WQI) using formula,

$$WQI = (\Sigma W_n * Q_n)/ \Sigma W_n).$$

Table 3: Water Quality Classification Based on WQI Value.

Water Quality Index Level	Water Quality Status
<50	Excellent
50-100	Good Water
100-200	Poor Quality
200-300	Very poor
>300	Water unsuitable for drinking

Results and Discussions

Table 4: Comparison with Standards

Parameter	Mean of 46 samples	Standard	Samples under acceptable limit	Samples outside permissible limit	% of samples under permissible limit
pH	7.65	6.5-8.5	27	1	96.43%
EC(µ/cm)	1189	1000-2000 (µ/cm)	28	0	100%
TDS (ppm)	773	500-2000 ppm	28	0	100%
Chloride	162.5	250-1000 mg/l	28	0	100%
Total Hardness	592.4286	200-600 mg/l	20	8	71.43%
Iron	0.12	1 mg/l	28	0	100%
Magnesium	72.38	30-100 mg/l	23	5	82.14%
Bi – carbonate	480.4286	200-600 mg/l	20	8	71.43%
Potassium	6.7	1-5 mg/l	12	16	42.86%
Fluoride	0.09	1-1.5 mg/l	28	0	100%
Calcium	118.06	75-200 mg/l	26	2	92.86%
Sodium	87.2	1-60 mg/l	5	23	17.86%
Nitrate	8.1	45 mg/l	28	0	100%
Sulphate	107.1786	200-400 mg/l	28	0	100%
Turbidity	2.1464	1-5	28	0	100%

Table 5: The analytical results showing quality of ground water in the study area

pH	Turbidity (NTU)	EC (µs)	TDS (mg/l)	HCO3- (mg/l)	Cl (mg/l)	TH (mg/l)	Ca2- (mg/l)	Mg2- (mg/l)	Na (mg/l)	K (mg/l)	F- (mg/l)	SO2- (mg/l)	NO3- (mg/l)	Fe (mg/l)
8.06	3.4	1235	803	180	152	568	128.26	60.26	104.8	11.6	0.050	139	12.5	0.42
7.53	3.5	1270	826	468	216	692	136.27	85.54	87.2	11.2	0.068	160	3.5	0.20
7.63	2.2	1323	860	744	96	572	101.00	77.76	134.4	6.2	0.113	117	8.5	0.00
7.53	2.3	1370	891	620	172	552	91.38	78.73	132.0	6.6	0.113	130	2.5	0.00
7.00	2.4	1428	928	672	156	588	11.22	136.08	127.2	9.2	0.170	129	7.0	0.10
7.00	2.9	1460	949	588	190	552	101.00	72.90	122.4	13.8	0.095	154	8.0	0.20
7.45	2.5	1570	1021	704	206	600	112.22	77.76	140.0	4.6	0.130	152	13.5	0.28
7.68	2.8	1208	785	420	156	468	104.21	50.54	124.8	6.0	0.053	154	13.5	0.00
7.81	2.1	900	585	476	46	496	91.38	65.12	68.8	5.0	0.108	97	13.0	0.00
8.93	2.3	353	229	160	10	280	52.91	35.96	17.0	2.8	0.043	57	7.0	0.00
7.25	2.4	1490	969	280	336	760	152.30	92.34	79.2	4.4	0.033	99	8.0	0.68
7.00	2.3	509	331	120	88	356	56.11	52.49	17.4	1.8	0.113	32	3.5	0.18
7.81	2.6	1247	811	708	102	496	91.38	65.12	129.6	6.0	0.168	80	7.0	0.16
7.63	2.5	140	91	76	6	80	16.03	9.72	16.2	1.4	0.010	48	5.0	0.12
8.22	2.7	936	608	392	104	472	76.95	68.04	68.8	3.6	0.030	111	11.5	0.10
7.53	1.3	1304	848	436	182	1648	336.67	196.34	149.6	11.0	0.055	193	2.0	0.00
7.00	3.2	924	601	460	136	492	113.83	50.54	60.6	4.6	0.180	89	12.0	0.54
7.80	2.3	776	504	672	56	308	78.56	27.22	68.4	5.8	0.218	77	10.0	0.00
8.25	1.4	876	569	368	136	400	92.99	40.82	65.4	4.2	0.225	93	2.0	0.00
7.80	2.1	1085	705	472	176	500	96.19	63.18	82.4	4.8	0.145	70	10.5	0.00
7.00	1.2	871	566	388	116	464	141.08	27.22	34.8	4.2	0.050	97	1.5	0.00
7.00	2	868	564	368	136	420	107.41	36.94	36.4	3.4	0.085	100	11.0	0.40
7.96	2	1410	917	572	176	560	134.67	54.43	104.0	2.2	0.100	107	9.0	0.00
7.93	1	1541	1002	748	216	824	145.89	111.78	79.2	16.6	0.028	107	12.0	0.00
7.75	1.7	1688	1097	684	256	868	157.11	115.67	77.6	8.6	0.075	92	9.0	0.00
7.85	1	1715	1115	576	276	868	177.96	103.03	97.6	8.4	0.130	94	7.0	0.08
7.64	0.6	1946	1265	532	376	844	208.42	78.73	113.6	12.8	0.125	103	7.5	0.00
8.23	1.4	1849	1202	568	276	860	192.38	92.34	103.2	6.4	0.070	120	10.5	0.00

Table 6: Statistical analysis of water Samples from Bidadi

Parameter	Maximum value	Minimum value	Mean	Standard deviation
pH	8.93	7	7.65	0.4712
Turbidity	3.5	0.6	2.15	0.7033
EC	1946	140	1189	443.35
TDS	1264.9	91	773	288.18
Alkalinity	748	76	480.43	185.79
Cl	376	6	162.5	90.61
TH	1648	80	592.43	287.22
Ca	336.67	11.22	118.06	64.15
Mg	196.34	9.72	72.38	38.41
Na	149.6	16.2	87.2	39.67
K	16.6	1.4	6.7	3.82
SO_4	0.23	0.01	0.099	0.057
NO_3	193	32	107.18	36.04
F	13.5	1.5	8.1	3.69
Fe	0.68	0	0.12	0.18

pH

The pH of an aqueous solution is regulated by a series of related chemical reactions that either release or consume hydrogen ions (Hem 1985). No suggested pH safety recommendations exist. Despite the fact that pH values typically do not have a direct impact on users, they are one of the most important limitations on the quality of work water [8]. The pH level controls how acidic and alkaline freshwater is. Mainly tracked in groundwater are the quantity and chemical make-up of organic and inorganic molecules [9]. The pH ranges from 7 to 8.93 for samples of water. This demonstrates the water's mild basicity.

Alkalinity (Bi-carbonate)

Alkalinity is a measure of water's ability to resist changes in pH, also known as buffering. Maintaining a stable pH is critical for most applications. Bicarbonates and carbonates create alkalinity in water. Carbonates and bicarbonates are estimated from alkalinity values [10]. Bicarbonate varies from 76 to 748 mg/l in the study area.

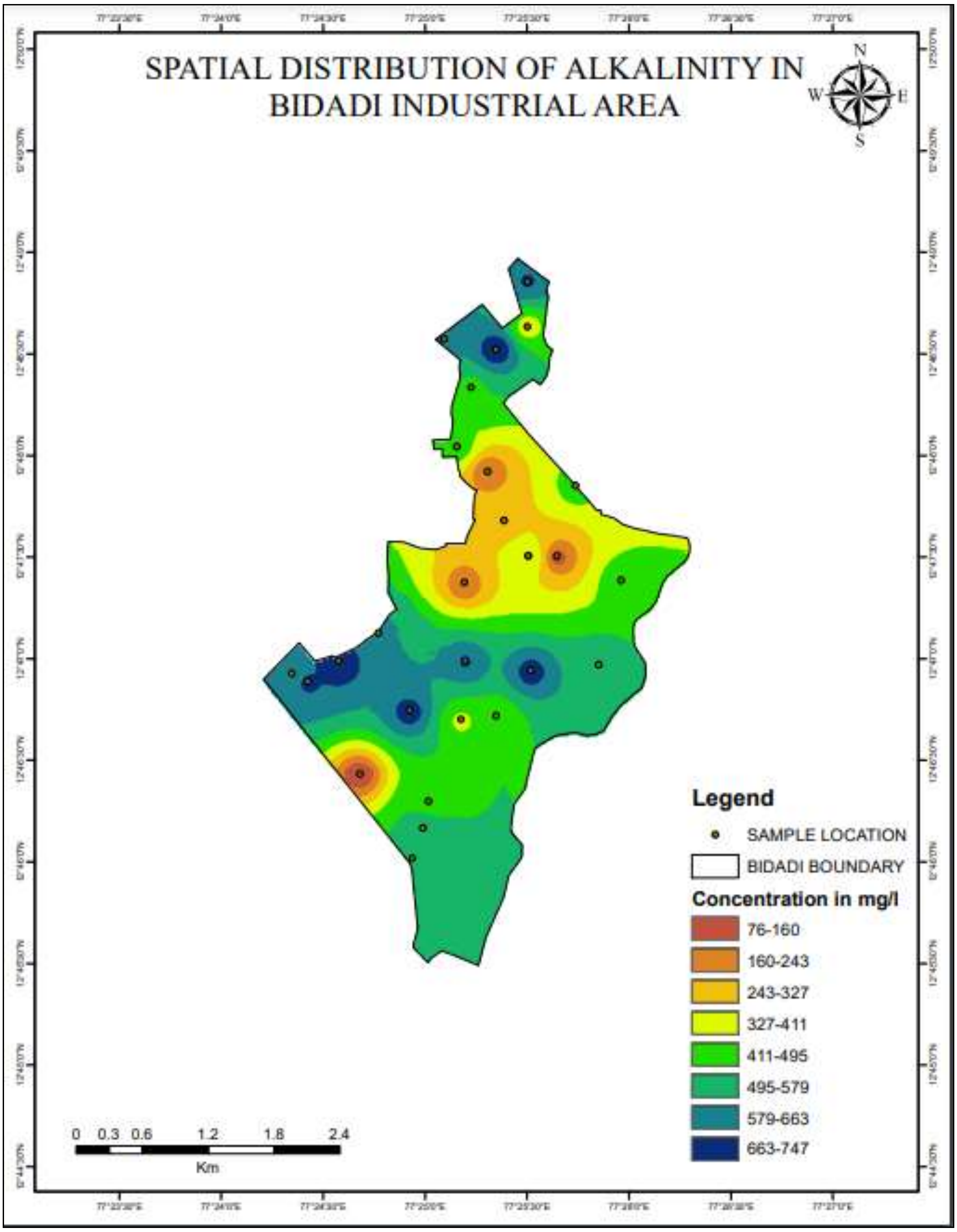

Fig 2: Distribution of Bi- Carbonates in Bidadi industrial area

Chlorides (CL)

Salts such as NaCl (sodium), KCl (potassium) and CaCl2 (calcium) contain chlorides and are widely distributed in nature. Weathering cycles absorb chlorides from multiple rocks in the water and soil. Cation is the taste threshold for chloride anions in water, based on: Perception thresholds for sodium chloride and calcium chloride in water range from 200 to 300 mg/L [11]. Chloride is essential for monitoring groundwater contamination from sewage. At concentrations over 250 mg/l, water procures pungent taste which is frightful to many individuals. Department of Indian Standards recommends 250 mg/l as admissible cut off and 1000 mg/l as helpful breaking point without any substitute source. The chloride focus in the review region is under 250 mg/l, Hence acceptable.

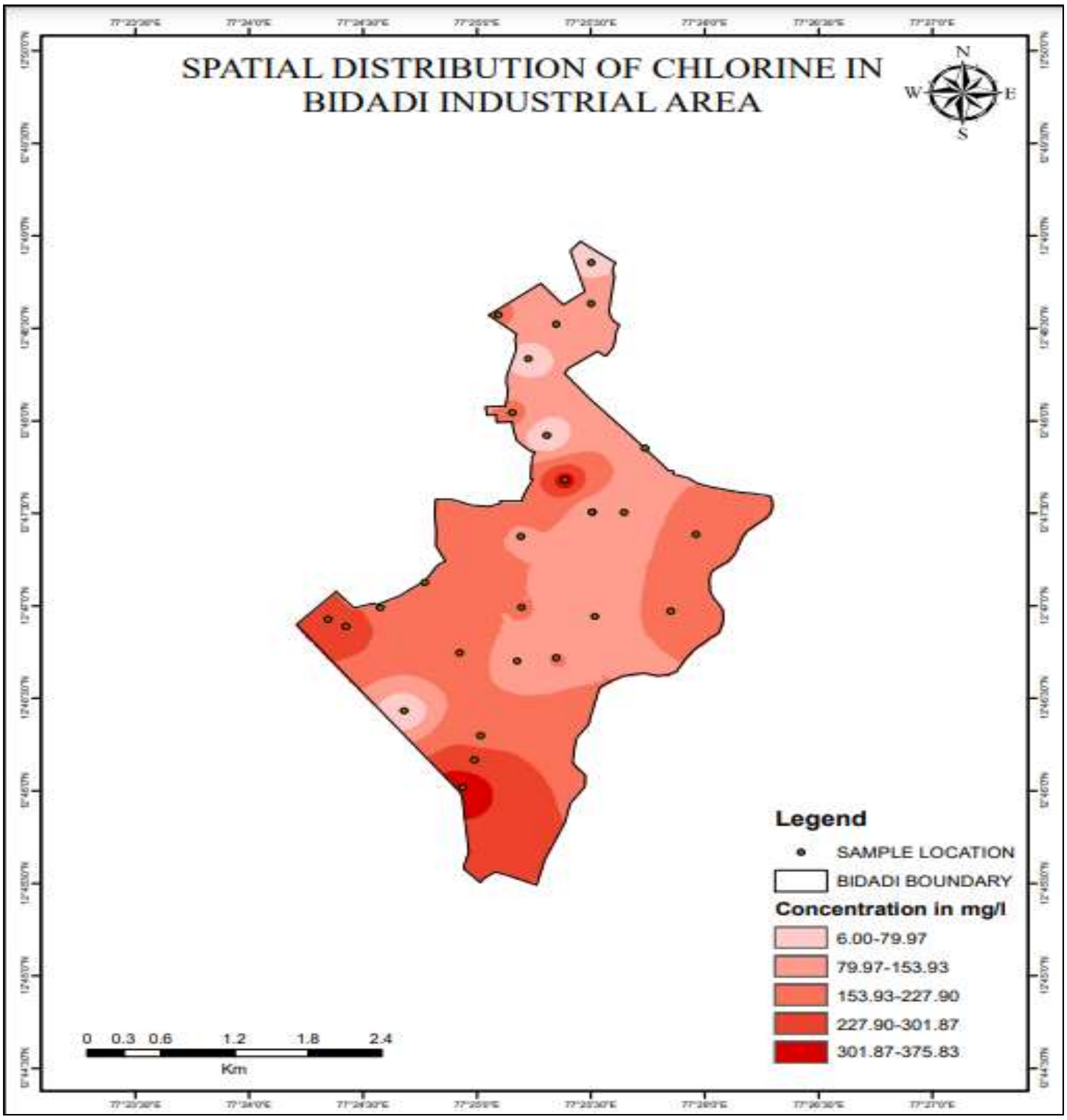

Fig 3: Distribution of Chlorides in Bidadi industrial area

Calcium Hardness

Water's calcium hardness is determined by the quantity of calcium ions in the water. Water with a significant mineral content is said to be "hard water." These minerals mostly consist of bicarbonates, chlorides, carbonates, and sulphates of calcium and magnesium. Typically, flooding and washing from limestone and chalk rocks dissolve minerals in water. Water hardness varies significantly from region to region even though there are strict standards for drinking water quality. High lime hardness drinking water has no recognised negative effects. Due to the fact that calcium and magnesium are crucial nutritional needs, hard water really has health benefits. Calcium also improves the taste of water. The WHO says that public acceptance of water hardness can vary greatly from region to region. They exhibit taste thresholds for calcium ions in the range of 100-300mg/L. They also specify that water with a hardness greater than about 200 mg/L can cause limescale, but these are guidelines only and do not set regulations or limits. Calcium hardness values range from 11.22 to 336.67 mg/l.

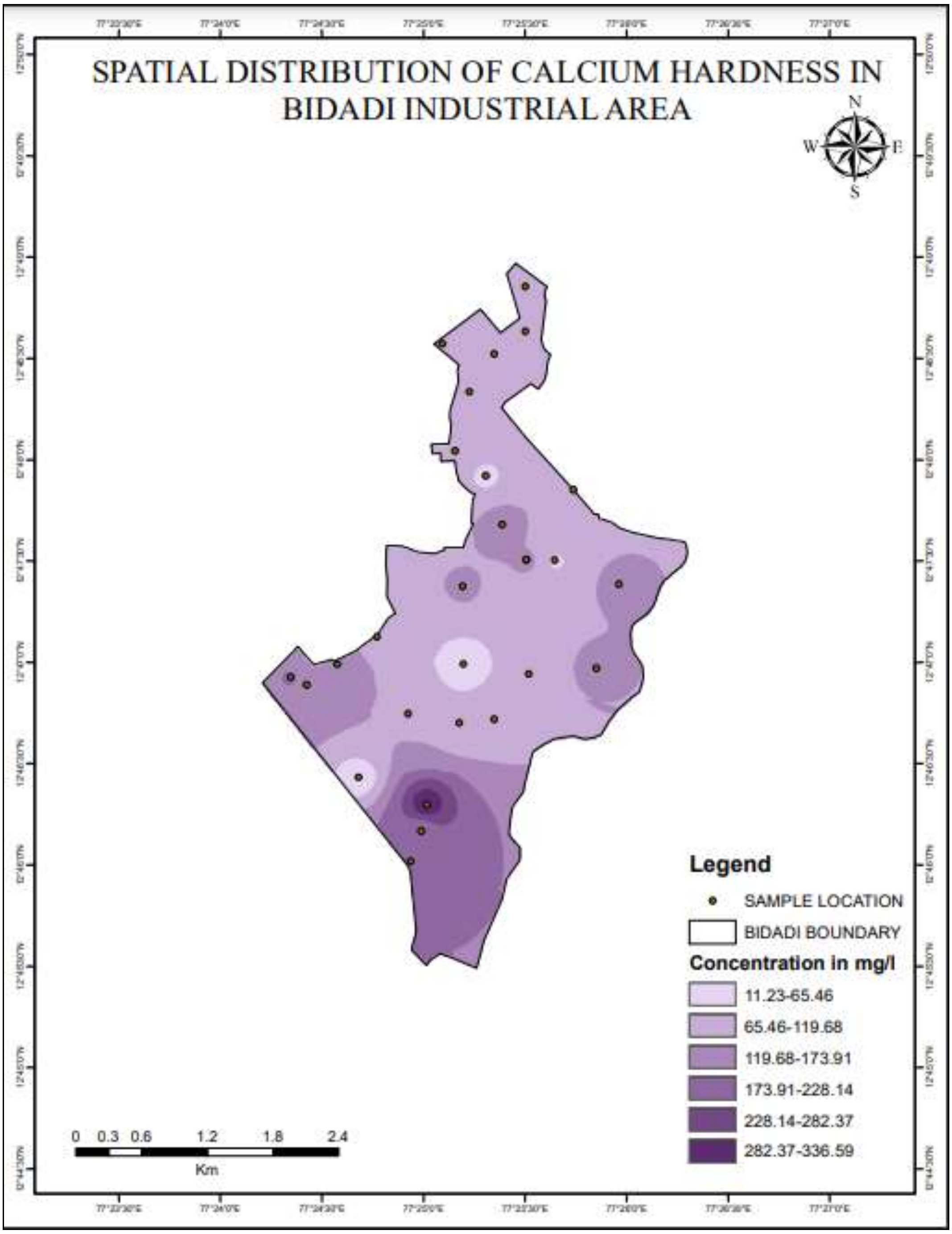

Fig 4: Distribution of Calcium Hardness in Bidadi industrial area

Electrical Conductivity (EC)

The amount of ionised substances in the water is related to its electrical conductivity, which shows the limit of electrical momentum that could pass through it. Many of the inorganic compounds that have broken down and are present in water have ionised structures and aid in electrical conduction. The electrical conductivity of water samples in the research area ranges from 140 to 1946 S/cm.

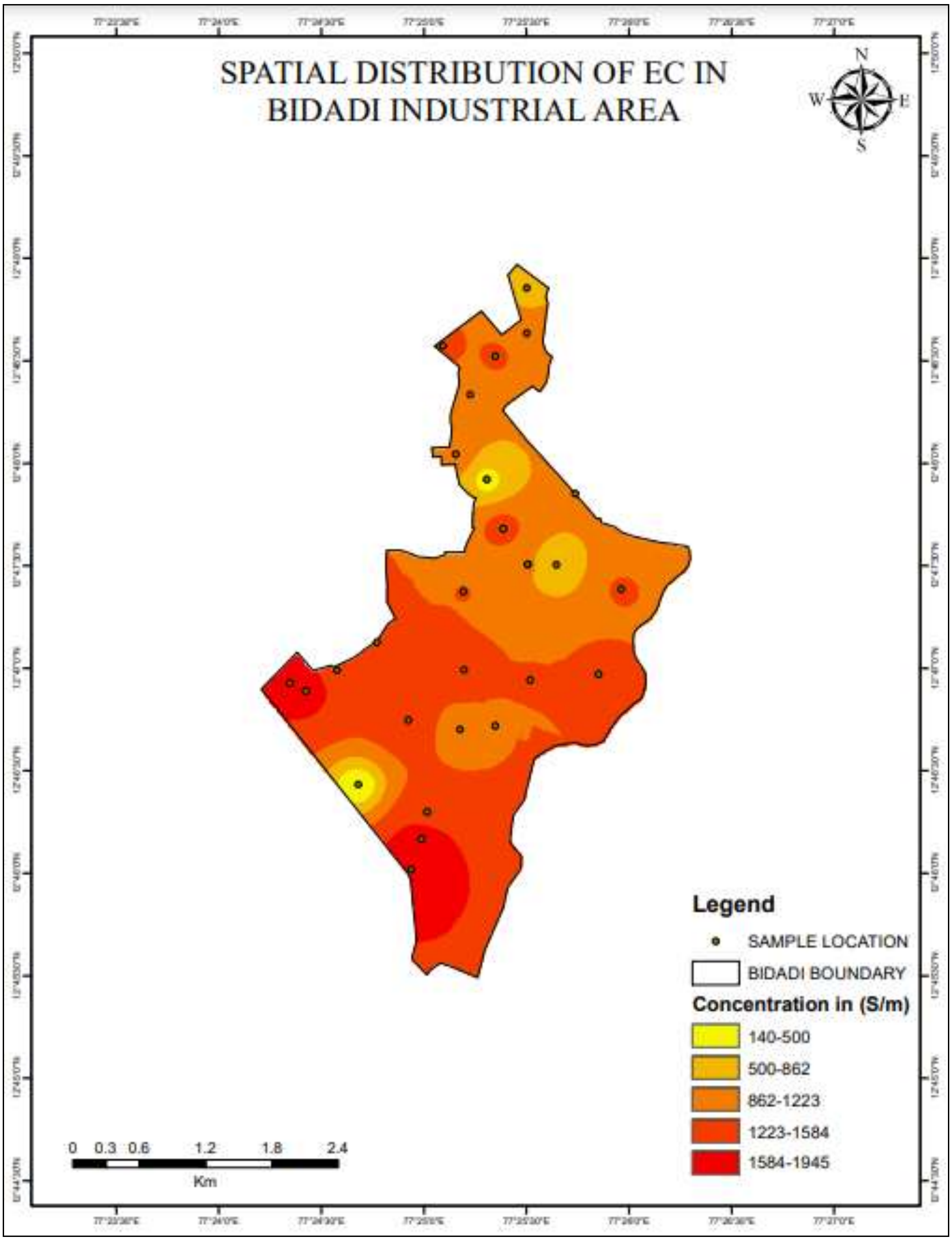

Fig 5: Distribution of Electrical Conductivity in Bidadi Industrial Area

Iron

Iron is naturally present in rivers, lakes and groundwater. It can also be released into water from anthropological sources such as industrial waste and corroded iron pipes. Iron can exist in water in two forms: soluble iron (Fe^{2+}) or insoluble iron (Fe^{3+}). Iron in drinking water can come from corrosion of iron pipes. In addition, since natural water often contains a lot of iron, it is common to remove iron during treatment of drinking water. Iron is an essential organic component for all living organisms and is present in the hemoglobin skeleton. According to Haloi and Sharma [12], Mn can promote iron bacteria in groundwater. High Iron fixation causes mild toxicity. The outcomes showed that the groupings of iron during the winter season falls within the permissible limits of the study area.

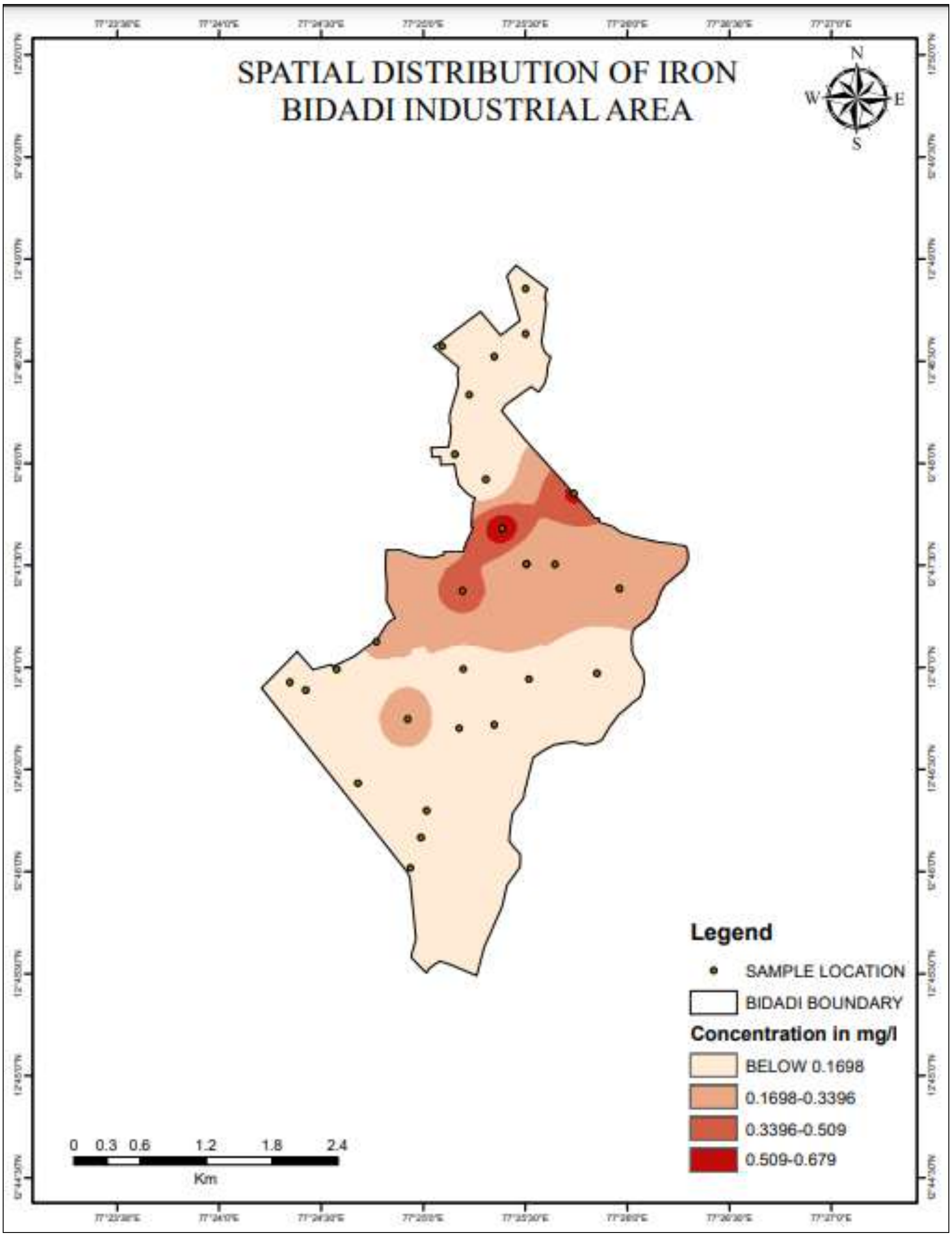

Fig 6: Distribution of Iron in Bidadi industrial area

Fluoride

Fluoride is fundamental for individuals as a minor component and higher centralization of this component cause harmful impacts. Grouping fluoride in drinking water between 0.6 and 1.0 mg/L protects against caries and improves bone disease. Department of Indian Standards has proposed a permissible limit for fluoride in drinking water of up to 1.0 mg/L and a tolerance range of up to 1.5 mg/L. Consuming water with fluoride fixation above 1.5 mg/L leads to fluorosis, tooth staining and bone disease. In the study area, fluoride ranges from 0.01 to 0.23 mg/L.

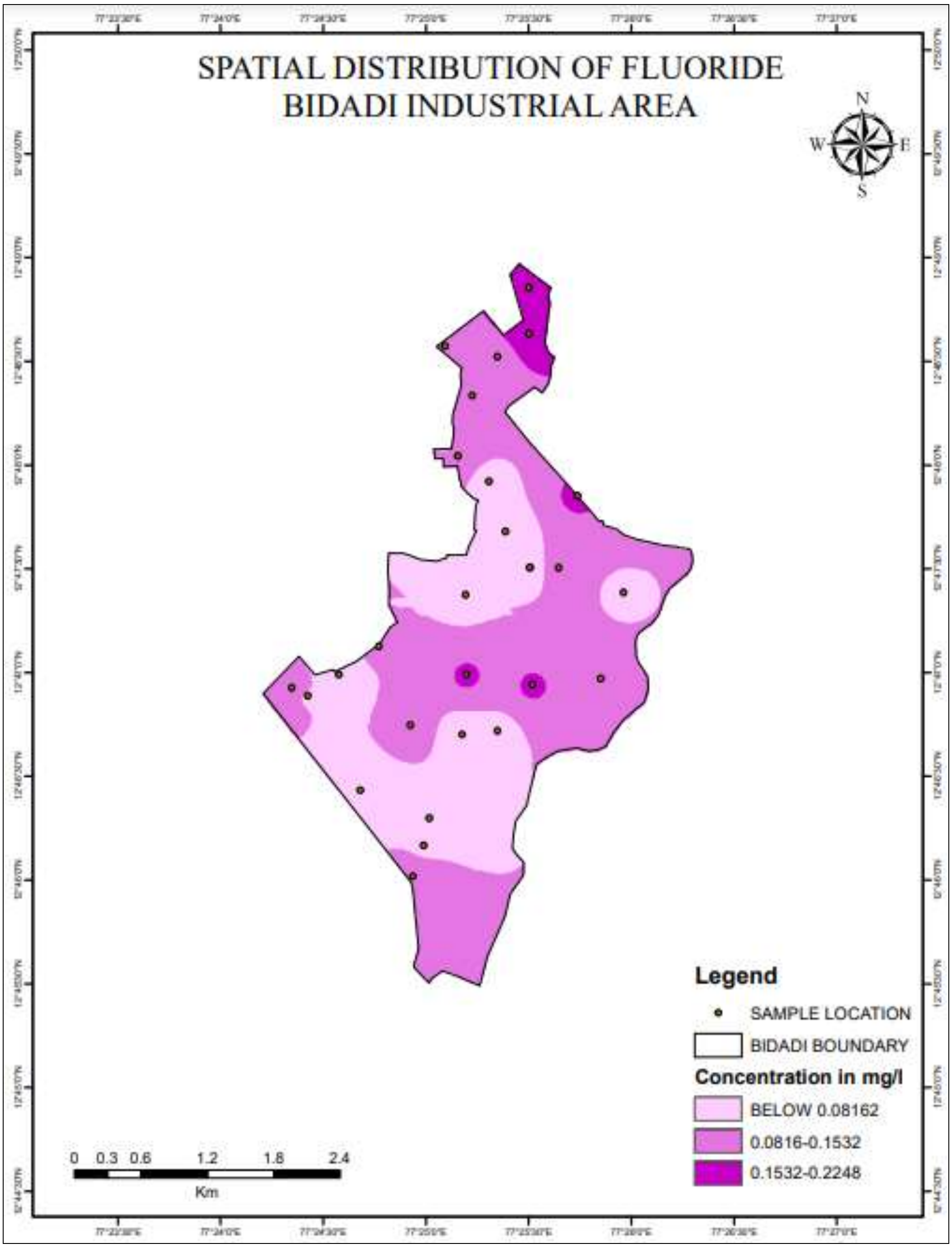

Fig 7: Distribution of Fluoride in Bidadi industrial area

Magnesium Hardness

Magnesium ions are among the most essential minerals known to humans and are abundantly present in our surroundings. After Iron, Oxygen, and Silicon, Magnesium is the fourth most common element on Earth. At the cellular level, they are responsible for more than 300 enzymatic reactions that enable the human body to function. Magnesium in water is a completely normal phenomenon. Found in most rivers, streams and seas. Infection from one organism to another spreads unknowingly into the environment. As it passes from one organism to another, it's unknowingly spread across the environment.

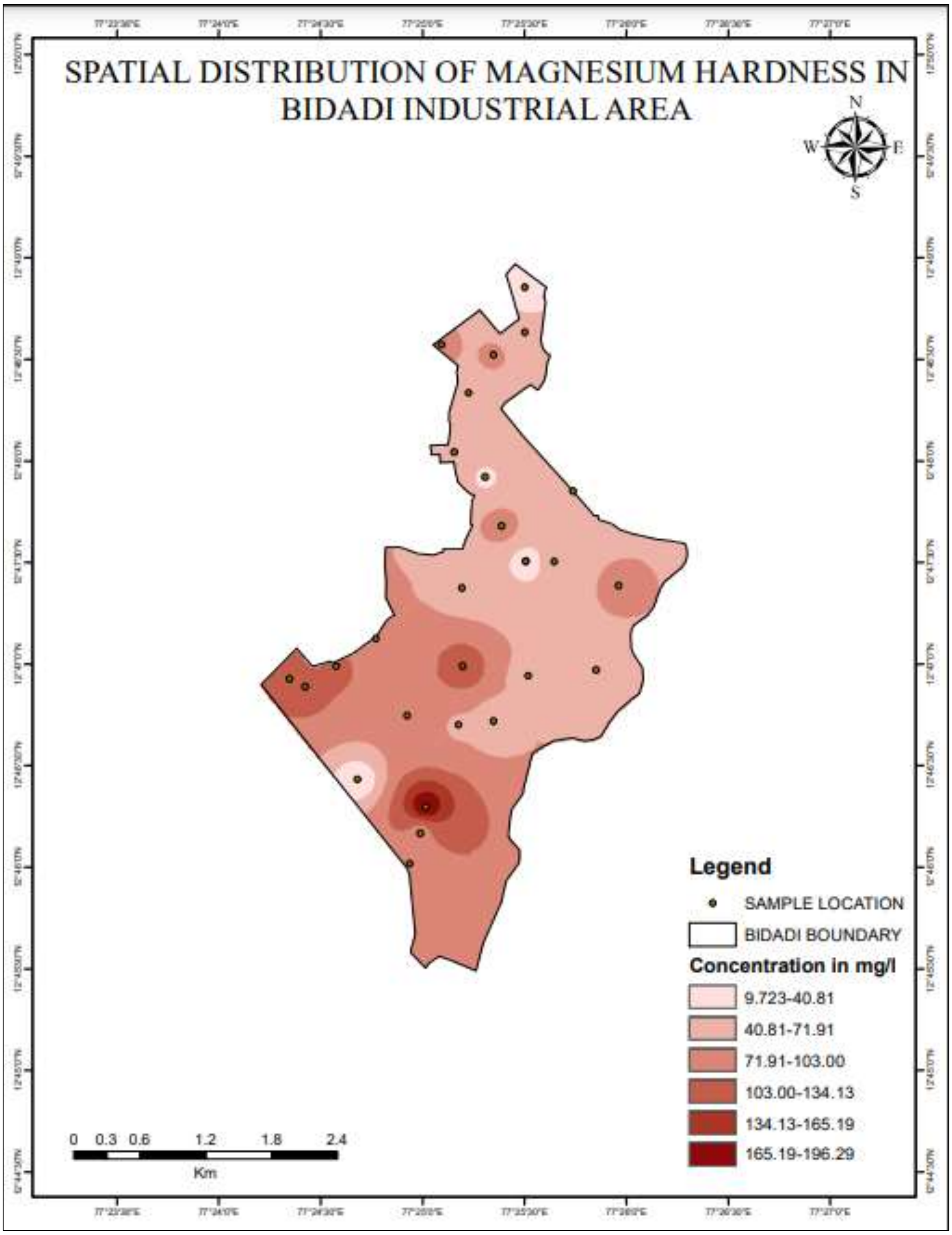

Fig 8: Distribution of Magnesium in Bidadi industrial area

Potassium

Potassium is slightly rarer than sodium in volcanic rocks, but is abundant in each of the sedimentary rocks. Potassium is a basic component of plants and living organisms. Components present in plant material are lost from horticultural soils through harvesting, germination, and filtration, eventually becoming natural sediments.

Potassium values range from 1.4 to 16.6 mg/l. However, [13] WHO does not establish health-based guideline values for K and P in drinking water.

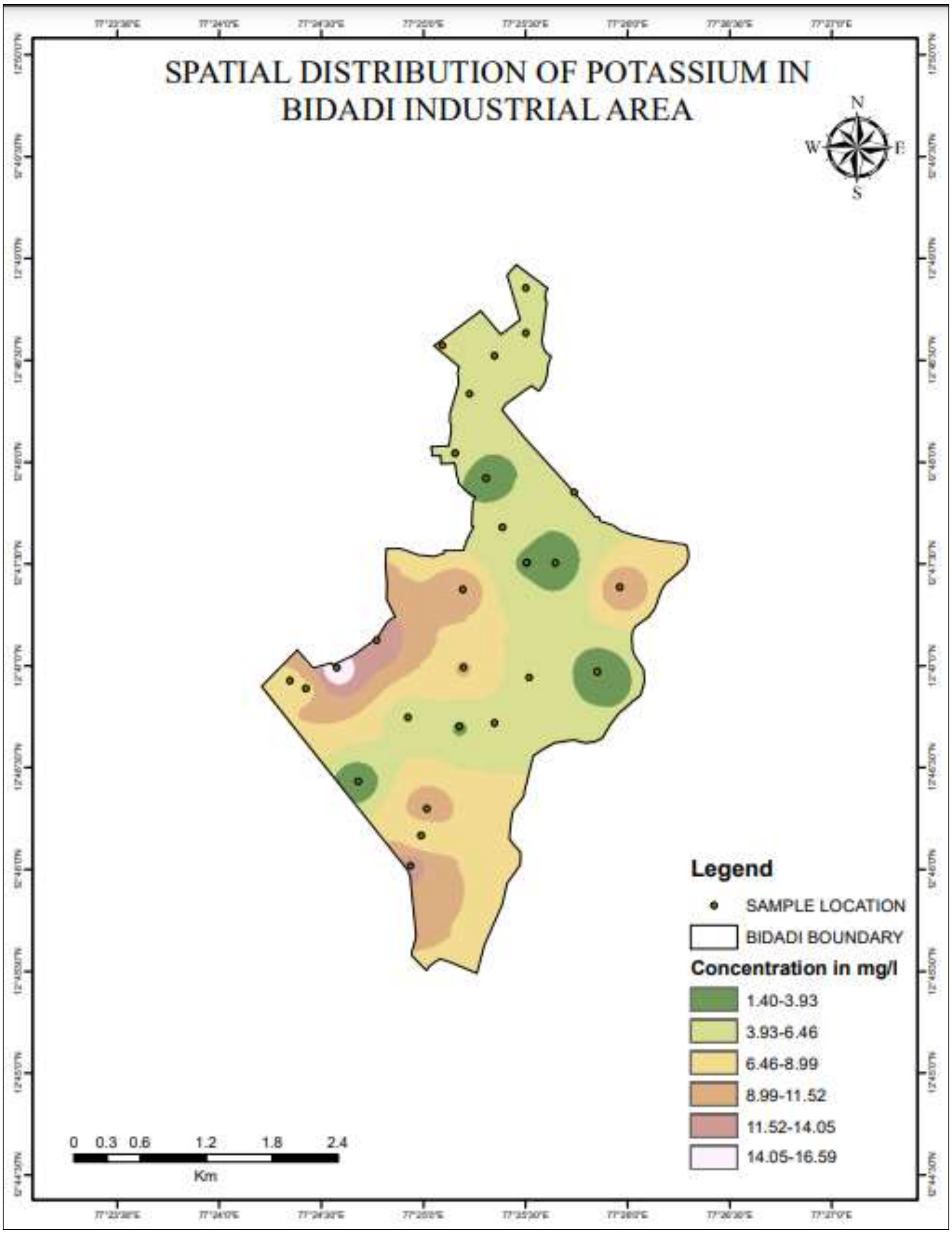

Fig 9: Distribution of Potassium in Bidadi industrial area

Total Dissolved Solids (TDS)

Total Dissolved Solids is a measure of the total amount of impurities in drinking water. According to a common definition, "dissolved solids" must be less than 2 microns in order to flow through the filter. Total Suspended Solids are regarded as particles greater than 2 microns. The EPA classifies Total Dissolved Solids as a "secondary contaminant." Overall, people view them as more of a nuisance than a threat. However, some water contaminants that contribute to total dissolution can be harmful to your health in the long run if they are present in excess amounts.

The water samples' mean TDS concentrations ranged from 91 to 1264.9 mg/l

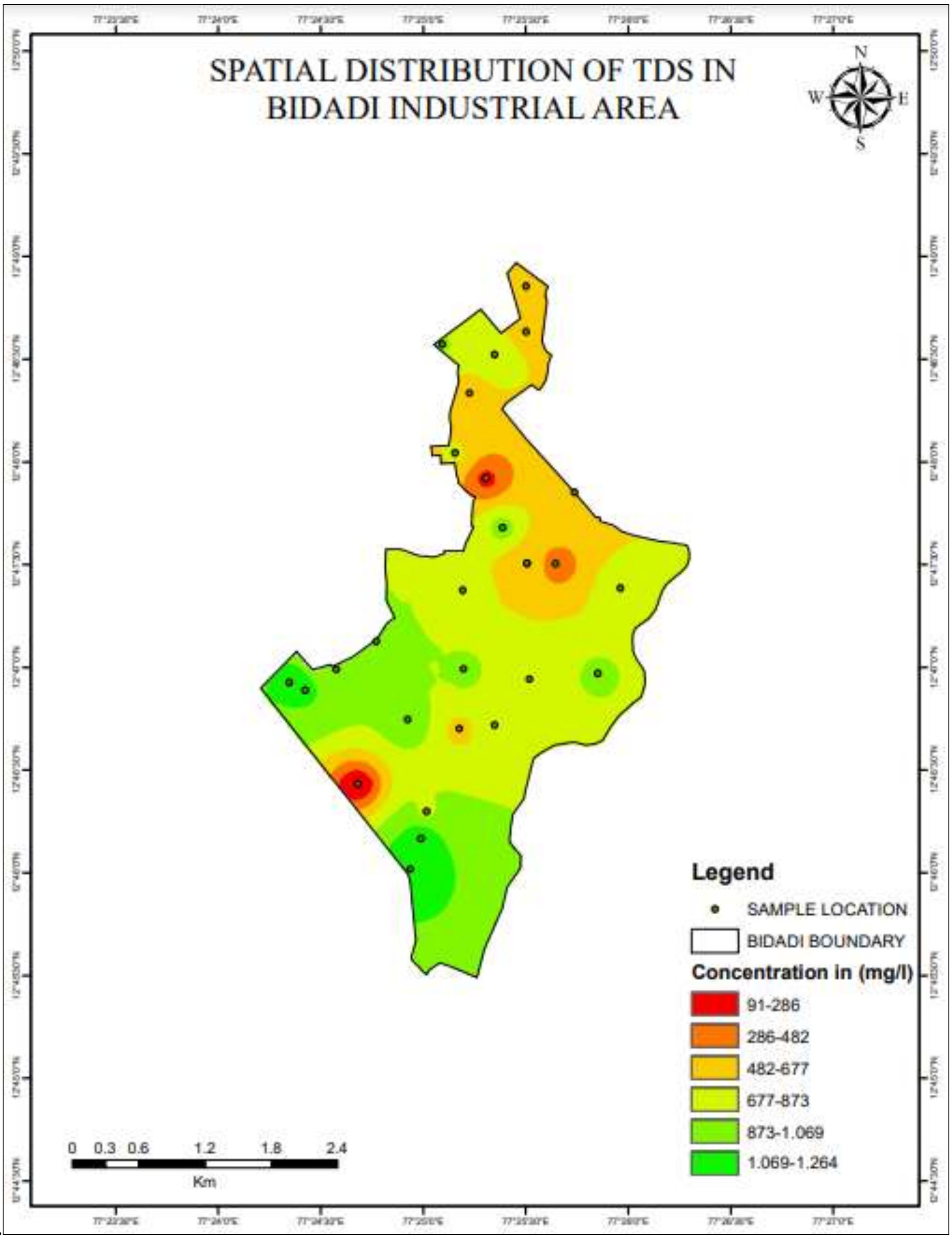

Fig 10: Distribution of Total Dissolved solids in Bidadi industrial area

Sulphates

Scale buildup in water pipes is brought on by sulphate minerals, which are also possibly responsible for the water's harsh taste. Potable water with high sulphate concentrations may have a laxative effect. The WHO states that there are no health-based recommendations for sulphate levels in water because these levels are typically not hazardous to human health. They do note that sulphates are unlikely to impact the taste of the water when present at concentrations below 250 mg/L.

The tables show that all samples with sulphate values below 200 mg/l fall within the limitations. The sulphate concentrations ranged from 32 to 193 mg/l.

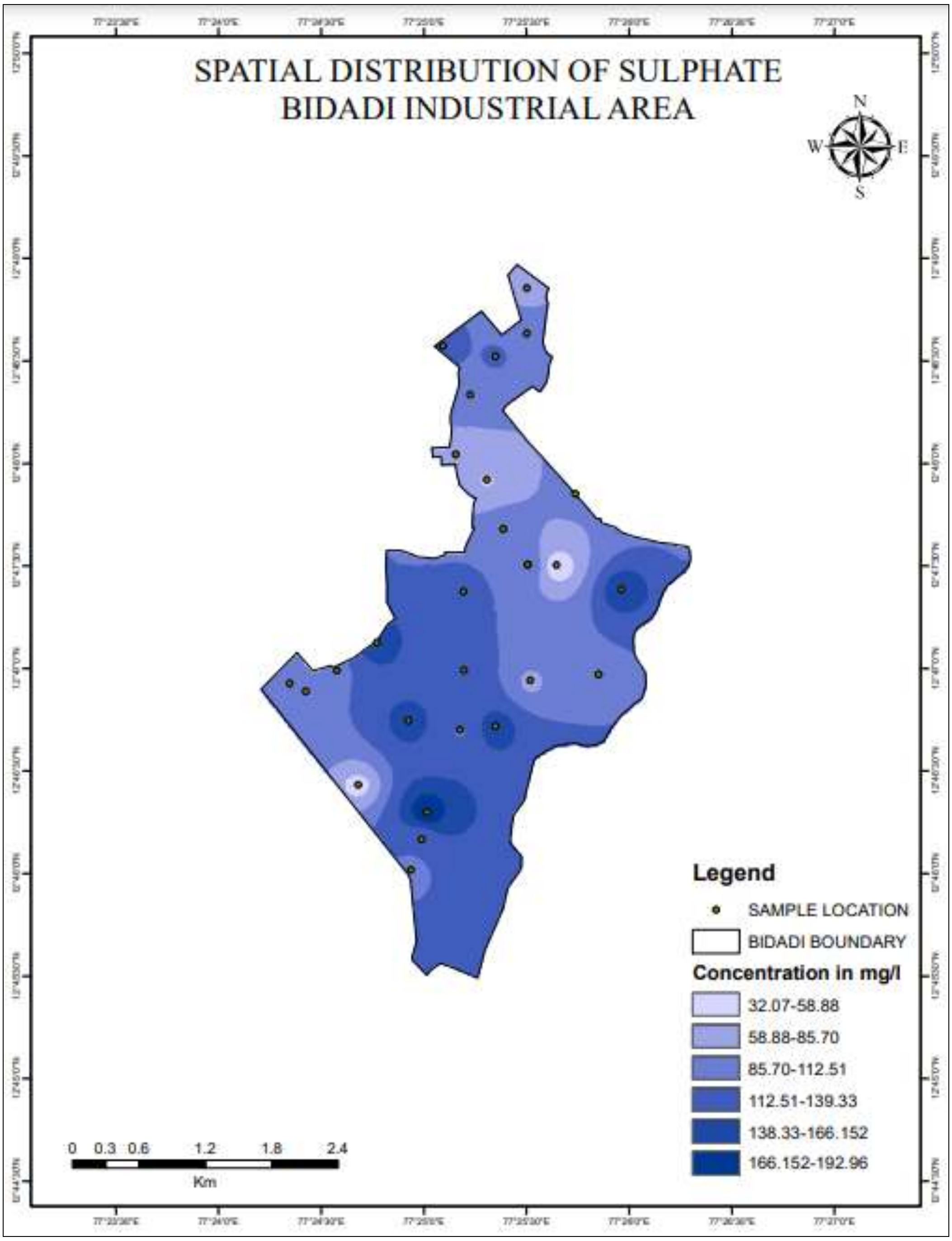

Fig 11: Distribution of Sulphates in Bidadi industrial area

Sodium

Higher upsides of sodium are found in the groundwater in the space of salt water interruption. Release of effluents like home-grown and modern and so on onto the ground is another source of sodium in water. Overall, mature kidneys excrete sodium efficiently, so sodium salts are not truly toxic to humans.. The mean upsides of sodium are shifted from 16.2 to 149.6 mg/l.

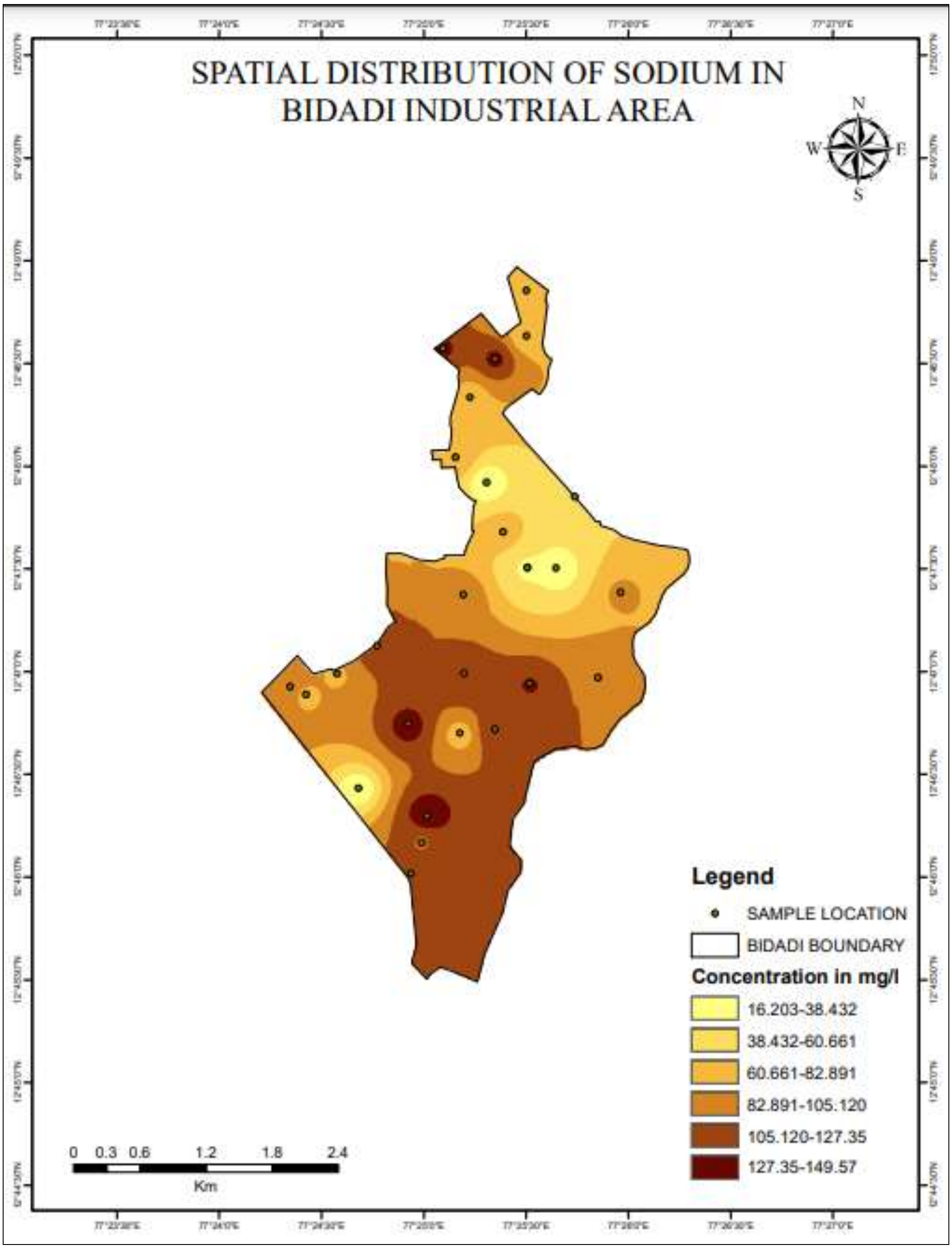

Fig 12: Distribution of Sodium in Bidadi industrial area

Total Hardness

All out hardness is a proportion of the limit of water to the centralization of calcium and magnesium in water and is generally communicated as what might be compared to $CaCO_3$ focus. In the current review, the all-out hardness of the water sample ranges somewhere in the range of 80 to 1648 mg/l.

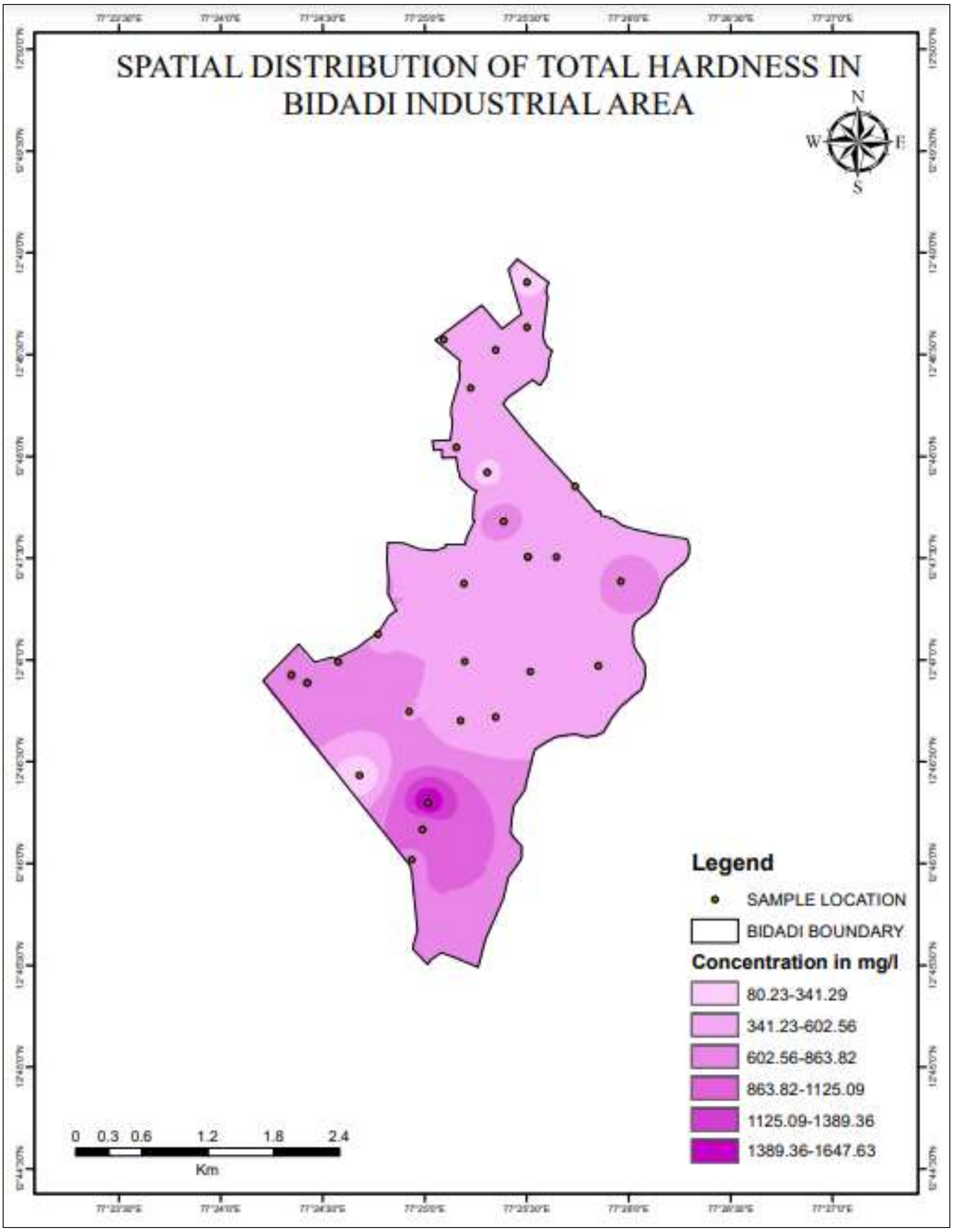

Fig 13: Distribution of Total Hardness in Bidadi industrial area

Turbidity

Turbidity is an important parameter of drinking water. Turbidity monitoring is used to measure the water treatment efficiency of drinking water. Changes in turbidity in drinking water can have many causes. This may indicate a malfunctioning filter, a problem with the water, a lack of effective disinfection, or poor coagulation and flocculation. WHO has set a limit that the turbidity of drinking water should not exceed 5 NTU and ideally should be less than 1 NTU. Spatial turbidity variation shows that the north has higher concentration/turbidity values, ranging from 0.6 to 3.5 NTU.

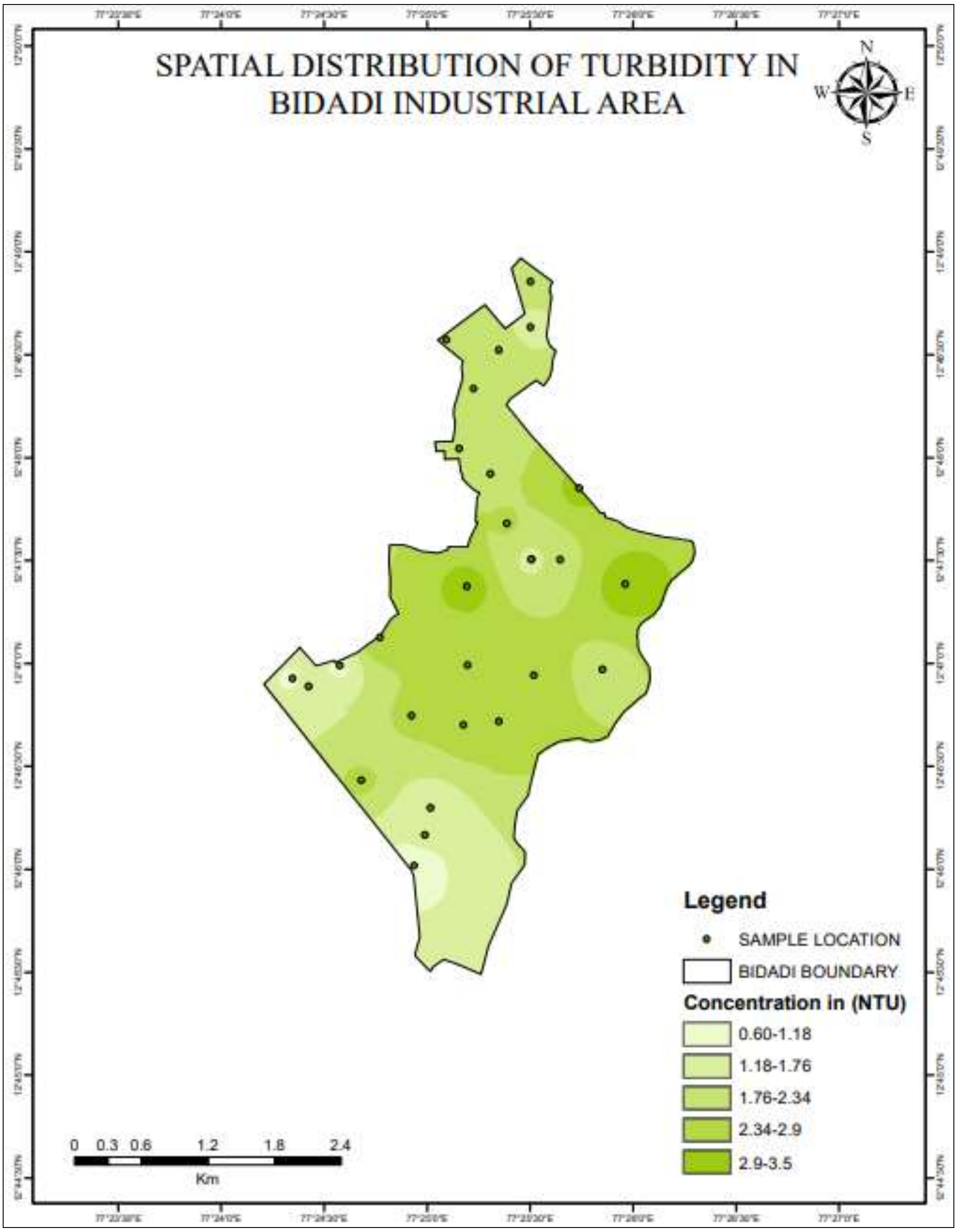

Fig 14: Distribution of Turbidity in Bidadi industrial area

Conclusion

- The Chloride, Bio-carbonate, Nitrate, sulphate, Fluoride, and Electrical conductivity content in all the samples are within permissible range.
- The study area has shown some water samples, were exceed the permissible limit out of 46 water samples percentage, pH exceeds 3.57%, Total Hardness exceeds 28.57%, Magnesium exceeds 17.85%, Potassium exceeds 57.14%, calcium exceeds 7.14% and Sodium exceeds 82.14%.
- Overall WQI of Bidadi industrial area is Good (50.75). Hence no risk found in present situation of water.
- Iso-contour maps are prepared for all the quality parameter by using ARCGIS Software and spatial variation is analysed.
- The Bidadi industrial area presently growing day by day due to increase population and also industries near city and village. In order to keep a close eye on water quality and a healthy environment for people and the community, more trustworthy, effective, and quick monitoring measures must be implemented.

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