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Geospatial Distribution of Fluoride and Iron in Natural Water Sources in Mangalore City

Sharanya Kushalan[1] Anusha Kashyap[1] Shaiesh Morajkar[2] Smitha Hegde[1]

[1] Division of Bioresource and Biotechnology, Nitte University Centre for Science Education and Research (NUCSER), Nitte Deemed to be University, Deralakatte, Mangalore, Karnataka, India
[2] Parvatibai Chowgule College of Arts & Science (Autonomous), Gogol, Margao, Goa, India

Address for correspondence Smitha Hegde, PhD, Division of Bioresource and Biotechnology, Nitte University Centre for Science Education and Research (NUCSER), Nitte Deemed to be University, Deralakatte, Mangalore 575018, Karnataka, India (e-mail: smitha.hegde@nitte.edu.in).

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Abstract

Water is the most essential substance that supports life on earth. Animals and plants require water for their survival. Since water is being lost or used by our body, it is essential to replace it constantly. Humans need clean, potable water for consumption and to meet their daily hygiene needs. However, increased anthropogenic activities have caused a drastic increase in heavy metals in fresh waters. Heavy metals interfere with the normal physiology of the human body. It binds to cellular components, leading to dysfunction of the metabolic processes in our body. This study was undertaken to study the geospatial distribution of selected heavy metals in open-well waters within Mangalore City Corporation limits. Mangalore is perched strategically on the path of rapid development, heading toward becoming a smart city in India. Water samples were collected from all 60 wards in the jurisdiction of Mangalore City Corporation. The fluoride concentration was estimated using the spectrophotometric method using the Sodium 2-(parasulfophenylazo)-1,8-dihydroxy3,6-naphthalene disulfonate (SPADNS) reagent. Similarly, iron was estimated using the phenanthroline reagent. The findings report that the pH of the samples was acidic in 20 wards. Panambur, Kunjathbail North, Mannagudda, Court and Cantonment water was colored. Kunjathbail (North), Kunjathbail (South), Kambala, Kadri North, Bendoor, Bolar, Mannagudda, and Markada, showed high turbidity levels. The fluoride concentration in the samples collected from 60 wards of Mangalore city was less than 1.5 ppm, which is the permissible limit by the World Health Organization. Iron is within the permissible limit except for the wards Court and Boloor, which showed an iron concentration of 0.4 ppm and 3.08 ppm, respectively. However, arsenic was not detected in any of the 180 samples collected from the 60 wards of Mangalore City Corporation.

Keywords
- geospatial distribution
- well water
- fluoride
- iron
- arsenic
- pH
- color
- turbidity
- Mangalore city

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Introduction

Groundwater plays a significant role in sustaining human life to climate change and variations. The importance of groundwater increases even more as extreme climatic conditions intensify (floods, droughts), causing surface water and soil moisture precipitation. Groundwater and surface water interaction is complex to understand. The interaction of groundwater and surface water causes natural recharge and discharge processes. These biogeochemical interactions occur within a few centimeters beneath the sediments.[1,2] Groundwater is crucial for millions of families in urban and rural families. The estimated consumption of water is vast and diverse. When the natural process gets disturbed, it eventually causes a change in groundwater quality. Industrial waste, sewage, solid waste, food production, disposal, and other waste have caused an imbalance in our aquatic ecosystems. These imbalances have resulted in groundwater pollution with pathogens, pesticides, heavy metals, nitrate, arsenic, fluorides, etc.[2] The groundwater contamination is documented, and 18 Indian states show the presence of fluoride in their surface and ground water.[3]

Water pollution is caused by natural elements such as humus materials, minerals, soil, gases, and waste created by animals and living organisms on land and in water. The inorganic minerals like calcium, magnesium, sodium, and potassium and heavy metals like iron, manganese, mercury, nickel, and arsenic are harmful if present above the permissible limit.[4] Metal contamination in recent years in the aquatic environment has attracted global attention due to its toxicity, abundance, and persistence. Rapid population growth and intensive domestic activities, expanding industry, and agricultural production release many hazardous heavy metals into rivers. Water quality problem is also seen in rivers in urban areas due to the discharge of untreated domestic and industrial waste, which contains a high concentration of heavy metals.[5]

Fluoride (also written [F] −) is an inorganic, monatomic anion, typically white or colorless salt. It is odorless but with a distinctive bitter taste.[6] Fluoride is a form of mineral essential for healthy teeth and bones. It is found naturally in water, soil, air, plant, and rocks.[7] Mineral such as fluoride is sparingly soluble in water. It is negatively charged and highly unstable. It reacts immediately to form fluoride compounds. pH, Ca, HCO_3, and specific conductivity are parameters that influence the dissolution of fluoride into groundwater.[8] Since 1973 there has been a long history in India on the harmful effects of fluoride on humans and animals. Though mainly occur due to the high fluoride consumption in water, food, fumes, and toxic environment.[8,9] Drinking water is not always the primary fluoride source; however, it is sometimes added to public water to prevent dental caries. Deep groundwater from drilled might be bacteriologically safe but often not suitable due to naturally occurring chemicals. Surface water may have lower chemical concentration but can be fecal contamination.[10,11] The permissible limit of fluoride in drinking water by the World Health Organization (WHO) is 0.8 to 1.5 mg/L, and the Indian Council of Medical Research is 1.0 mg/L.

Iron is the second most abundant element in the earth's crust. Five percent of the iron in the environment is in its elemental form. Iron, one of the elements with essential nutrition, is present in the blood, as it plays a crucial role in oxygen transport and DNA synthesis. The amount of iron ingested from food in the body controls its availability. Iron deficiency can cause anemia, whereas excessive iron can cause serious diseases.[12] The WHO's permissible limit of iron in drinking water is 0.3 mg/L.

Arsenic is a naturally occurring element, distributed in the groundwater and crust of the earth. It is present in trace amounts in the air and several food items, particularly crustaceans and seafood. Arsenic is released into the environment as a result of weathering, mining, and other natural occurrences like volcanic activity.[13] Millions are affected by arsenic poisoning globally due to occupational and environmental exposure, as well as purposeful suicide and homicide attempts.[14] The WHO's permissible limit of arsenic in water is 10µg/L. The present study elucidates the geospatial distribution of fluoride, iron, and arsenic content in natural drinking water sources of Mangalore city. The resulting variable factors of pH, color and water turbidity across the 60 wards of Mangalore Municipal Corporation are discussed.

Materials and Methods

Study Area

Mangalore is situated on the western coast of Southern Karnataka. The study area is a tropical river basin, and has humid climate of peninsular India. Mangalore with an area of 132.4 km^2 is situated between 12°50′30″ N to 13°01′00″N and 74°48′0″ E to 74°55′00″ E coordinates (►**Fig. 1**). Mangalore is guarded by the thick forest of the Western Ghats in the east, the Arabian Sea in the west, and the southern boundary is shared with Kerala and Udupi districts in the north. The city's geology has sandy soil on the shoreline and laterite in a hilly region with natural valleys. In 1865, the Mangalore City Corporation was established, with 60 wards (►**Fig. 1**). Mangalore is the district headquarters of Dakshina Kannada. Mangalore has experienced dramatic urbanization in the last few years. Presently 0.09 mm^3 is supplied every day. City residents largely depend on the well water of their respective homes or apartments. The demand has touched 0.1 mm3 leading to severe stress on the existing drinking water supply. By the year 2026, it is estimated that the city's water demand will reach up to 0.25 million mm^3 per day.

Water Sample Collection

Water samples were collected from wells having natural water sources from 60 wards of Mangalore City Corporation. The water sample was collected using sterile falcon tubes during the month of January and February. Samples were collected in triplicates from each ward in the city. The Latitude and Longitude of each well were noted for geotagging.

A

B

60 wards of Mangalore City Corporation

1. Surathkal(West)	21. Padavu (West)	41. Central Market
2. Surathkal (East)	22. Kadri Padavu	42. Dongerkery
3. Katipalla (East)	23. Derebail (East)	43. Kudroli
4.Katipalla Krishnapura	24. Derebail (South)	44. Bunder
5.Katipalla (North)	25. Derebail (West)	45. Port
6. Iddya (East)	26. Derebail (South-west)	46. Cantonment
7. Iddya (West)	27. Boloor	47. Milagres
8. Hosabettu	28. Mannagudda	48. Kankanady-Valencia
9. Kulai	29. Kambla	49.Kankanady
10. Baikampady	30. Kodialbail	50. Alape (South)
11. Panambur	31. Bejai	51. Alape (North)
12. Panjimogaru	32. Kadri (North)	52. Kannur
13. Kunjathbail (North)	33. Kadri (South)	53. Bajal
14. Marakada	34. Shivabagh	54. Jeppinamogaru
15. Kunjathbail (South)	35. Padavu (Central)	55. Attavar
16. Bangrakulur	36. Padavu (East)	56.Mangaladevi
17. Derebail (North)	37. Maroli	57. Hoige Bazaar
18. Kavoor	38. Bendoor	58. Bolar
19. Pachanady	39. Falnir	59. Jeppu
20. Tiruvail	40. Court	60. Bengre

Fig. 1 (**A**) Map showing the Mangalore City Corporation study areas consisting of 60 wards. (**B**) List of wards chosen for the study.

Analysis of Chemical Parameters

Collected water samples were analyzed for chemical parameters such as pH, and color measured as Hazen unit, turbidity measured as Formazin attenuation units (FAU), fluoride (mg/L), and Iron (mg/L).

Estimation of Fluoride Concentration in Samples

The fluoride content was estimated in water samples using the SPANDS method. Pipette out 10 mL of the sample and add 10 mL of the acid zirconyl-SPADNS reagent. Once the color was developed, it was read against the absorbance under 570 nm using a spectrophotometer. The following absorbance was plotted onto the standard graph to obtain the unknown fluoride concentration in the sample.[15]

Estimation of Iron Concentration in Samples

Estimation of iron content in water samples was done using the phenanthroline method. To 10 mL of the sample in the standard flask, 1 mL of hydroxylamine hydrochloride and 5 mL of 1,10-phenanthroline were added, then 8 mL of sodium acetate buffer was added, then it was diluted to 100 mL, and then it was allowed to stand for 15 minutes for the color development, and finally, absorbance was measured at 508 nm. The concentration of iron in samples was estimated by plotting the absorbance in the standard graph.[16]

Detection of Arsenic in Water Samples

Arsenic in water samples was detected using the Arsenic Test Kit (WT025, Himedia, India). In brief, 5 mL of water sample was subjected to strip test in reaction vessel. The strip test is sensitive at the range 0.05 to 3.0 mg/L.

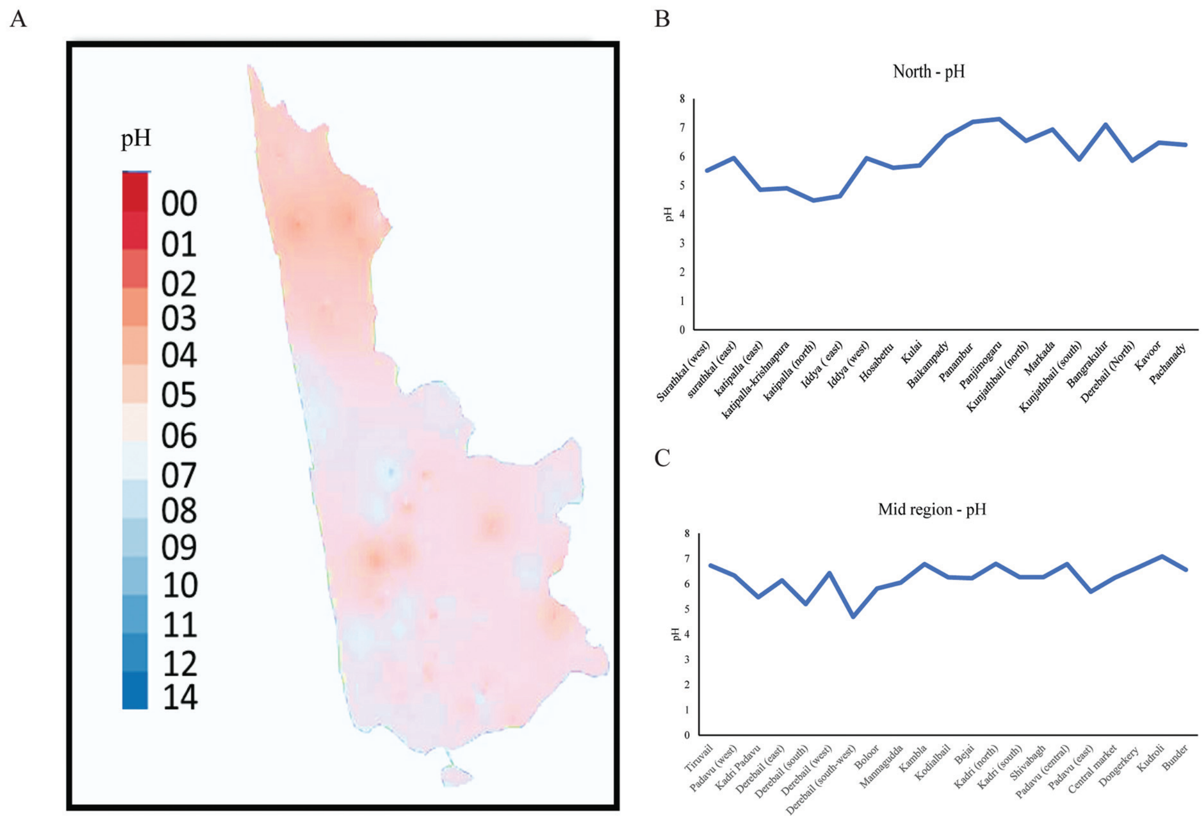
Statistical Analysis

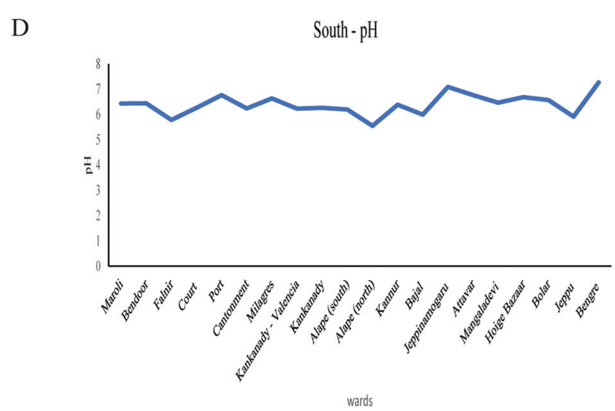
Triplicate samples collected from every ward were analyzed. The results are expressed as mean ± standard error values.

Results

The groundwater of Mangalore city within corporation limits has a pH range between 6 and 8.5 (►**Fig. 2A**). The acidic pH of the water is attributed to the laterite soil of the region. Neutral pH was seen in the sandy coastal regions of Panambur, Panjimogaru, Bengre, and Bangrakulur (pH 7.2, 7.3, 7.27, and 7.10, respectively). Water with basic pH was seen in samples from Kudroli and Jeppinamogaru 7.9 and 7.9, respectively. They were originally paddy cultivating fields reclaimed for housing and development. Thirty-four out of 60 wards showed pH around 6, whereas 20 wards out of 60 showed acidic pH (4.4–5.9) (►**Fig. 2B–E**).

Ideally, drinking water should have no visible color. The presence of iron, other metals, and natural impurities can





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	Acidic	Neutral	Basic	Total ward
North	11	8	0	19
Mid region	6	15	0	21
South	3	17	0	20

Fig. 2 (**A**) Map showing the varying pH concentration in groundwater of Mangalore city. (**B**) pH concentration in the groundwater of northern wards. (**C**) pH concentration in the mid-region wards. (**D**) pH concentration in the south region wards. (**E**) The number of wards showing the acidic and basic pH.

result in color development in the water sample. Color is estimated by the unit true color unit (TCU). Less than 15 TCU in Hazen is acceptable for consumption.[17] In the present study, samples from the wards such as Panambur (24.6 Hazen), Kunjathbail North (27.67 Hazen), Mannagudda (33.93 Hazen), Court (16.00 Hazen), and Cantonment (48.87 Hazen unit) showed excess color than the ideal requirement of 15.00 Hazen (►**Fig. 3**) making them unsuitable for drinking purpose. Samples from the rest of the wards were suitable for consumption (►**Fig. 3B–D**).

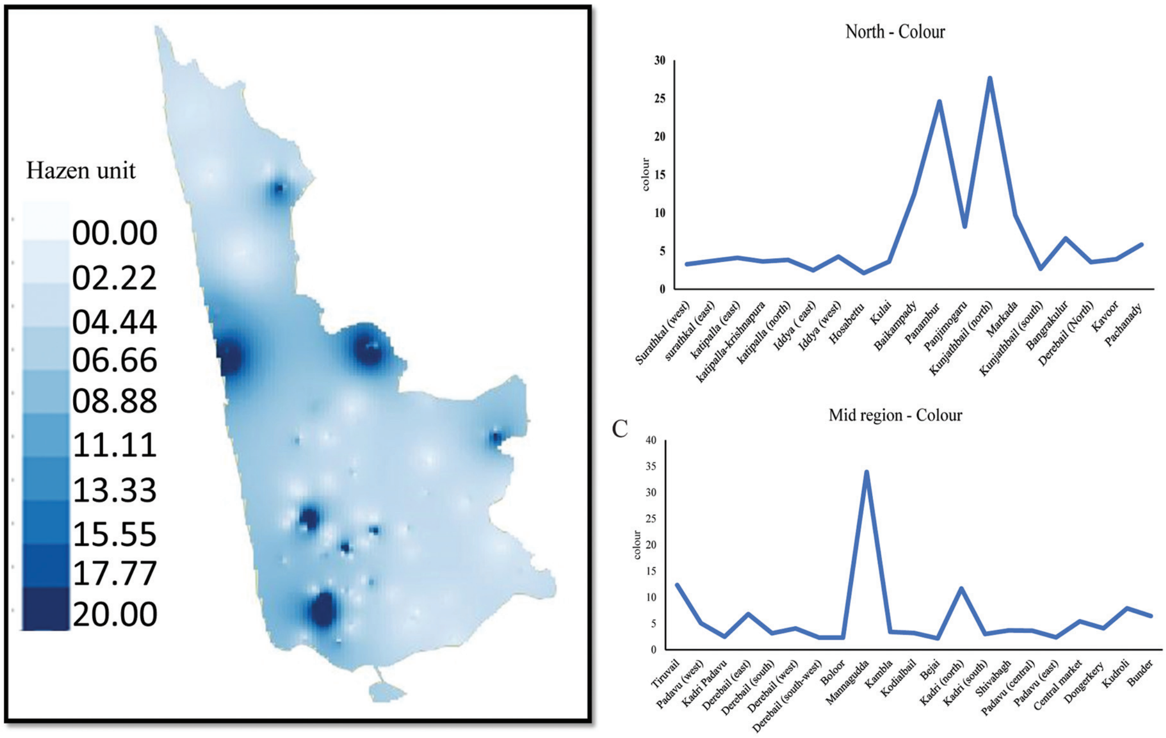
The turbidity of water samples was estimated using FAU units. It signifies that the instrument measures the transmitted light through the sample at 180 degrees of the incident light. This measurement was done using a spectrophotometer (780–900 nm).[18] Nineteen wards out of 60 showed turbidity of less than 1. Thirty-three wards have shown turbidity in the range of 1 to 5 FAU (►**Fig. 4A**). Kunjathbail (North), Kunjathbail (South), Kambala, Kadri North, Bendoor, Bolar, Mannagudda, and Markada showed turbidity greater than 5 (►**Fig. 4B–E**).

Fluoride is an element whose lower concentration is beneficial and harmful when consumed in a higher concentration.[8] Fluoride concentration was estimated using the SPADNS method for the samples from Mangalore city, which showed results under the permissible limit (< 1.5 mg/L) (►**Fig. 5A**). The concentration of fluoride was under the range of 0.6 to 0.9 mg/L (►**Fig. 5B–D**).

A

B

C



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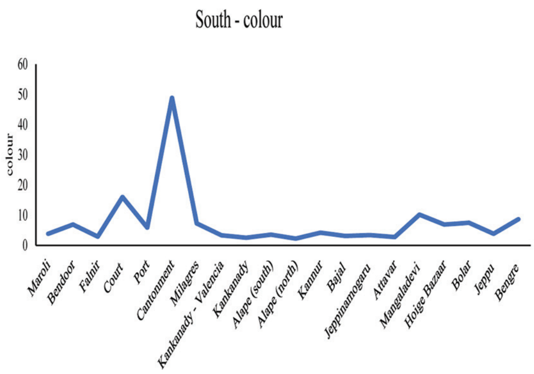

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	<15 Hazen unit	>15 Hazen unit	Total ward
North	17	2	19
Mid region	20	1	21
South	18	2	20

Fig. 3 (A) Map showing the gradient color concentration of groundwater in Mangalore city. (**B**) Color concentration in the groundwater of northern wards. (**C**) Color concentration in the groundwater of the mid-region wards. (**D**) Color concentration in the groundwater of the south region wards. (**E**) The number of wards showing less than 15 Hazen unit and more than 15 Hazen unit.

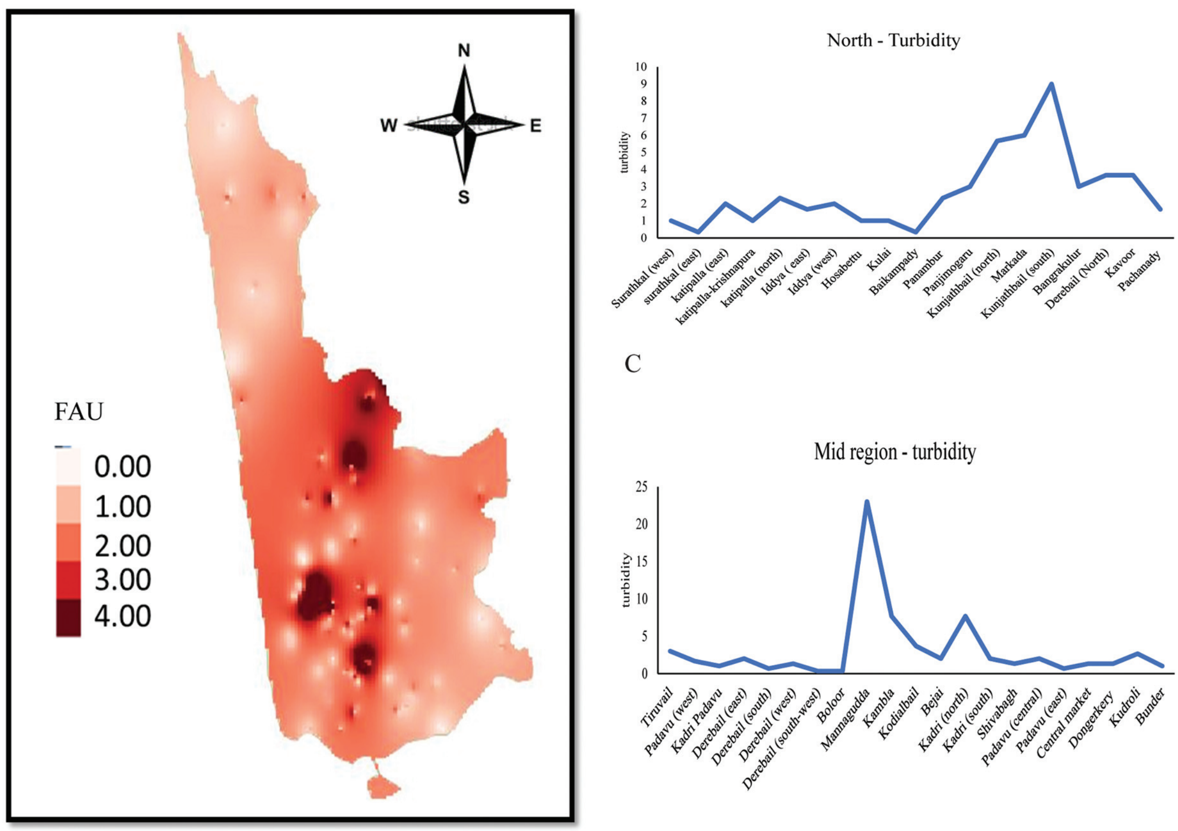
Iron is released into water either by corrosive water pipes, industrial contamination, or bacterial contamination. The concentration of iron causes varying color development in water samples.[19] In the study conducted, the concentration of iron was estimated by 1,10-phenanthroline method by using spectrophotometer which showed that the concentration of iron was under the permissible limit (< 0.3 mg/L) except in the ward Boloor and Court which showed higher concentration of iron 3.08 and 0.4 mg/L, respectively (►**Fig. 6A–D**).

Arsenic was not found in well waters in 60 wards of Mangalore City Corporation. Our study indicates that Mangalore area water is not contaminated with arsenic poisoning.

Discussion

Natural water chemistry is controlled by two fundamental factors such as its geology and water residence. The water's pH can determine the presence of heavy metals and the bioavailability of nutrients and their solubility. Different nutrients are absorbed best at suitable pH conditions, while acidic pH metals tend to occur.[8] In the present study, the pH of the water samples (180) in Mangalore city, around 20 wards, showed acidic pH on the scale of 4.4 to 5.9, whereas most of the samples were under the basic pH and neutral in pH (7.1 to 7.9). Our study is corroborated with a study conducted in Bangalore on the groundwater samples (1026). It showed a pH range from 5.51 to 9.93 indicating

A B C



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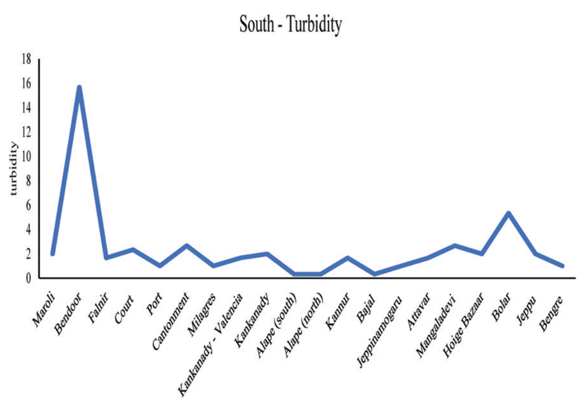

E

	<5 FAU	>5 FAU	Total ward
North	16	3	19
Mid region	18	3	21
South	18	2	20

Fig. 4 (**A**) Map showing the gradient turbidity concentration of groundwater in Mangalore city. (**B**) Varying turbidity in the groundwater of northern wards. (**C**) Varying turbidity in the groundwater of the mid-region wards. (**D**) Varying turbidity in the groundwater of the south region wards. (**E**) The number of wards showing less than 5 Formazin attenuation unit (FAU) unit and more than FAU unit.

a pH range in urban areas is mostly basic in nature. Similarly in a study conducted in Tumkur,[20] the pH of the groundwater samples was in the range of 6.6 to 8.9, indicating near neutral and alkaline pH of the water. Dissolved and suspended particles influence the watercolor. Transparent water, which has a low concentration of dissolved particles, appears blue. Brown or yellow water is seen due to dissolved organic matter or decaying plant matter. Some algae and phytoplankton present in water usually appear yellow and red color. Soil runoff water shows red, brown, and yellow colors in the water. Watercolor directs the source of water and its pollutants. Watercolor is divided into two types based on its solid materials–apparent and true color. The apparent color is the whole water sample color, which includes suspended and dissolved components, whereas true color is the color of the water after filtering the sample.[21] In this study, the samples was estimated for the color, and it was observed that the average was 6.98 TCU, whereas a study conducted in Canada[22] collected groundwater samples from 64 sites, and the average mean of color was 30 TCU, which is above the permissible limit. Similarly, study conducted in Finland[23] showed the color of the water ranging from 20 to 276 TCU.

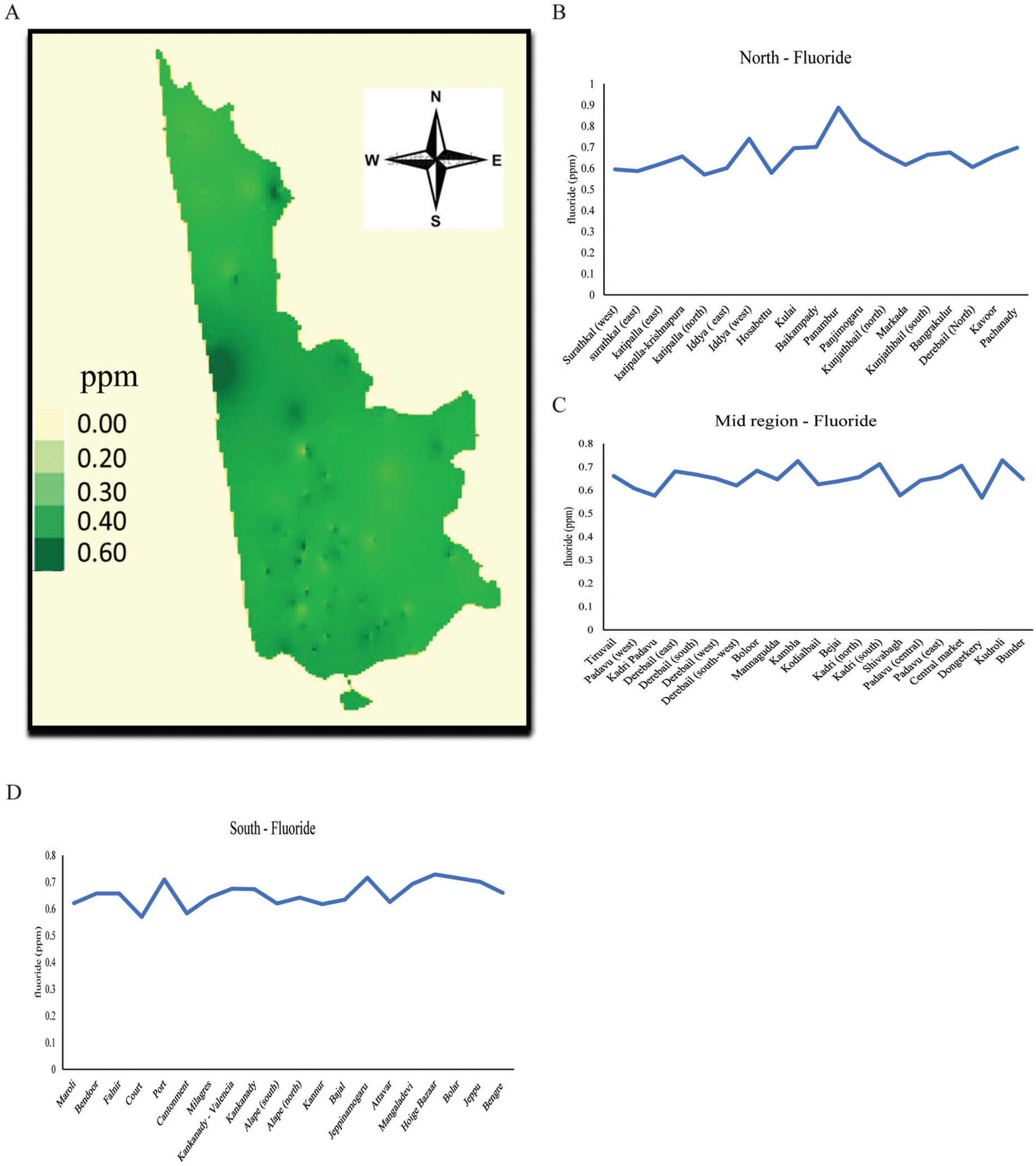

Fig. 5 (**A**) Map showing the gradient distribution of fluoride concentration in groundwater of Mangalore city. (**B**) Varying fluoride concentration in the northern wards. (**C**) Varying fluoride concentration in the mid-region wards. (**D**) Varying fluoride concentration in the groundwater of the south region wards.

The higher concentration of color in this area was due to the presence of phosphorous in higher amounts. We infer that the color of water in the wells of Mangalore area is in the range of permissible limit.

The cloudiness in the water is seen because of the fine suspended materials. These fine particles cause intense scattering of light. This phenomenon is known as turbidity. Thus, turbid water is said to those water with a high concentration of suspended materials and lower visual clarity. The presence of suspended materials causes light attenuation, reducing the visual range in water and the unavailability of light for photosynthesis. Nephelometric turbidity is an index of suspended particles by light scattering. Turbidity is a relative scattering measure and an essential parameter in the quality of water.[24] In this study, the water samples were subjected to measurement of turbidity. The turbidity of the water was in the range of 0 to 23, with an average of 2.76 TCU. A study conducted in Zimbabwe on the turbidity of samples, around 59% of the sample were under 5 TCU, which is below the permissible limit in WHO

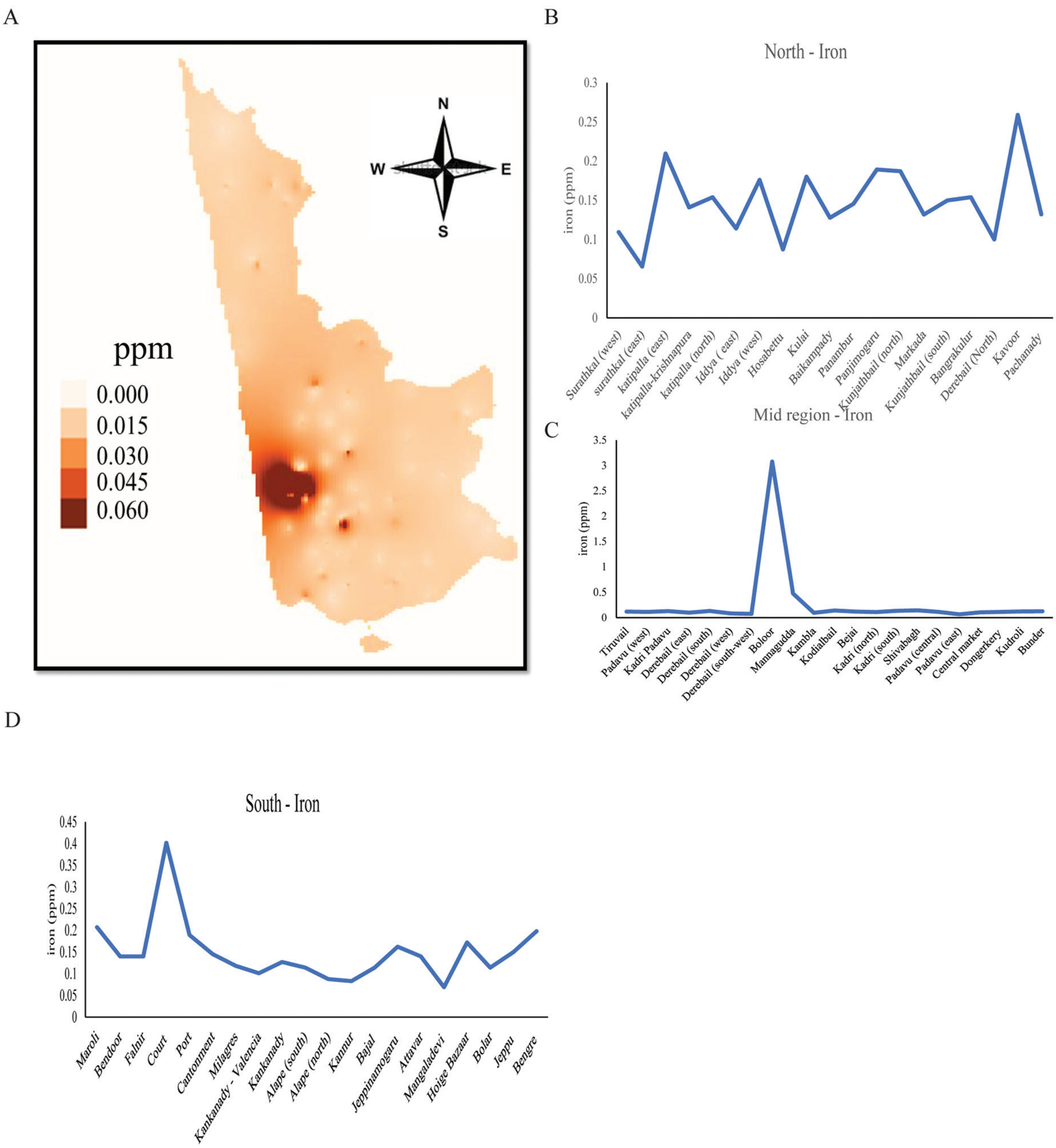

Fig. 6 (**A**) Map showing the gradient distribution of iron concentration in groundwater of Mangalore city. (**B**) Varying iron concentration in the groundwater of northern wards. (**C**) Varying iron concentration in the groundwater of the mid-region wards. (**D**) Varying iron concentration in the groundwater of the south region wards.

guidelines.[21] In another study conducted in Atlanta, the population suffered from a gastrointestinal illness. When the samples were estimated to measure turbidity, it was seen in the range of 1.1 TCU to 16.3 TCU. In the samples after the filtration, the turbidity was reduced from 0.03 to 0.17 TCU.[25]

Earth has only 0.6% of groundwater of the whole water resources. Since no treatment is required, it is mostly preferred by rural and urban areas. Anthropogenic activities, factory pollution, and solid wastes from the industry cause the leaching of contamination into the water.[26] One such contamination would be fluoride and iron. Fluoride leaches out from soil and rocks into the groundwater. In this study, the estimation of fluoride resulted in a range of 0.6 to 0.9 mg/L, which gives an average of 0.66ppm concentration in Mangalore city. This level is within the permissible limit in groundwater. A study in Hyderabad on fluoride concentration in groundwater was found to be in the range of 1.1 to 3.15 ppm beyond the permissible limit. Even higher concentrations were detected in industrial and residential areas.[27] In a study conducted in Mexico, the estimation of fluoride concentration was done by collecting samples from aquifers. It was found to be higher than the permissible limit. Higher fluoride concentration may be due to the toxic chemicals reaching the groundwater by geochemical process.[28] Our study indicates that well water samples of Mangalore city have fluoride concentration within the permissible limit.

The iron content in Mangalore well waters, showed an average concentration of 0.19 ppm, which is under the permissible limit (< 0.3 ppm). A study conducted in West Bengal showed a concentration of iron above 0.3ppm, indicating the study area was contaminated with iron.[29] Another study conducted in the Varanasi (Uttar Pradesh) urban area on the Indo-Gangetic plain showed an iron concentration of 0.9 ppm, which is higher than the permissible limit.[30]

Conclusion

In the present study, groundwater sources of Mangalore city in 60 wards were tested for pH, color, turbidity, fluoride, iron, and arsenic content. This study indicates that 33% of the samples were acidic in nature. Panambur, Kunjathbail Northward area, Mannagudda, Court, and Cantonment had colored water. Turbidity in water samples from Kunjathbail (North), Kunjathbail (South), Kambala, Kadri North, Bendoor, Bolar, Mannagudda, and Markada was high, whereas the sample from the Court region had iron content above the permissible limit (0.4 ppm), and in Boloor concentration of iron content levels was 10-fold higher (3.08 ppm). Iron in regions of higher concentration can be due to rapid urbanization activities. The iron content must be addressed by filtration or changing the corrosive metal water pipes with noncorrosive pipes. The acidic pH of the water is due to the presence of hard laterite soil in these areas. The color and turbidity of the water in the region are a sign of poor water management practices, making filtration and water treatment essential before consumption in these wards.

Fluoride was found to be under the permissible limit in all 60 wards. Fluoride is naturally present in the environment. Fluoride in smaller concentrations is beneficial, but it can cause dental and skeletal fluorosis when consumed in higher concentrations. Since the fluoride concentration in Mangalore city is under permissible limit, it can benefit consumers. Arsenic was not detected in any of the 60 wards of Mangalore City Corporation. A similar study can be undertaken for other heavy metals in Mangalore. It will help improve the water treatment procedure and regulate the concentration of the minerals in the drinking water of Mangalore city.

Authors' Contributions

We declare that all the authors have actively contributed to drawing up this manuscript. S.K. prepared the original manuscript and figures; A.K. conducted the study, S.M. was responsible for data analysis and figures; S.H. conceptualized, monitored the work, and reviewed the manuscript.

Conflict of Interest

S. H. reported all support for the present manuscript and grants or contracts from any entity from Nitte University Centre for Science Education and Research (NUCSER).
All other authors reported no conflict of interest.

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References

1 Taylor RG, Scanlon B, Döll P, et al. Ground water and climate change. Nat Clim Chang 2013;3(04):322–329
2 Sophocleous M. Interactions between groundwater and surface water: the state of the science. Hydrogeol J 2002;10(01):52–67
3 Sahoo NK, Rout C. Ground water: threats and management in India—a Review. Int J Geotechnics Environ 2012;4(02):143–152
4 Begum A, Ramaiah M, Khan I, Veena K. Heavy metal pollution and chemical profile of Cauvery River water. J Chem 2009;6(01): 47–52
5 Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Islam MK. Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. Ecol Indic 2015;48:282–291
6 Rickwood C, Carr GM. Global drinking water quality index development and sensitivity analysis report. United Nations Environment Programme (UNEP) & Global Environment Monitoring System (GEMS). Water Programme. 2007;1203:1196–1204
7 Fawell J, Bailey K, Chilton J, Dahi E, Magara Y. Fluoride in Drinking-Water. London, UK: IWA Publishing; 2006 Sep 30
8 Tahaikt M, El Habbani R, Haddou AA, et al. Fluoride removal from groundwater by nanofiltration. Desalination 2007;212(1–3):46–53
9 Agrawal M, Agrawal S, Adyanthaya BR, Gupta HL, Bhargava N, Rastogi R. Prevalence and severity of dental fluorosis among patients visiting a dental college in Jaipur, Rajasthan. Ind J Res Pharm Biotechnol 2014;2(04):1339–1344
10 Marinho VC, Higgins JP, Logan S, Sheiham A. Fluoride gels for preventing dental caries in children and adolescents. Cochrane Database Syst Rev 2002;2(02):CD002280
11 Indermitte E, Saava A, Karro E. Exposure to high fluoride drinking water and risk of dental fluorosis in Estonia. Int J Environ Res Public Health 2009;6(02):710–721
12 Kumar M, Puri A. A review of permissible limits of drinking water. Indian J Occup Environ Med 2012;16(01):40–44
13 Carlin DJ, Naujokas MF, Bradham KD, et al. Arsenic and environmental health: state of the science and future research opportunities. Environ Health Perspect 2016;124(07):890–899
14 Kuivenhoven M, Mason K. Arsenic toxicity. In: StatPearls.Treasure Island, FL: StatPearls Publishing; 2022
15 Haj-Hussein AT, Al-Momani IF. Indirect spectrophotometric determination of fluoride in water with zirconium-SPADNS by flow injection analysis. Anal Lett 1989;22(06):1581–1599
16 Tesfaldet ZO, van Staden JF, Stefan RI. Sequential injection spectrophotometric determination of iron as Fe(II) in multi-vitamin preparations using 1,10-phenanthroline as complexing agent. Talanta 2004;64(05):1189–1195
17 Mahananda MR, Mohanty BP, Behera NR. Physico-chemical analysis of surface and ground water of Bargarh District, Orissa, India. Int J Res Rev Appl Sci 2010;2(03):284–295
18 Davies-Colley RJ, Smith DG. Turbidity suspended sediment, and water clarity: a review 1. J Am Water Resour Assoc 2001;37(05): 1085–1101

19 Prakash KL, Somashekar RK. Groundwater quality–assessment on Anekal Taluk, Bangalore Urban district, India. J Environ Biol 2006; 27(04):633–637
20 Ramakrishnaiah CR, Sadashivaiah C, Ranganna G. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. J Chem 2009;6(02):523–530
21 Dzwairo B, Hoko Z, Love D, Guzha E. Assessment of the impacts of pit latrines on groundwater quality in rural areas: a case study from Marondera district, Zimbabwe. Phys Chem Earth Parts ABC 2006;31(15–16):779–788
22 Fallu MA, Allaire N, Pienitz R. Distribution of freshwater diatoms in 64 Labrador (Canada) lakes: species environment relationships along latitudinal gradients and reconstruction models for water colour and alkalinity. Can J Fish Aquat Sci 2002;59(02):329–349
23 Keskinen T, Marjomäki TJ. Growth of pikeperch in relation to lake characteristics: total phosphorus, water colour, lake area and depth. J Fish Biol 2003;63(05):1274–1282
24 Sajidu SM, Masamba WR, Thole B, Mwatseteza JF. Groundwater fluoride levels in villages of Southern Malawi and removal studies using bauxite. Int J Phys Sci 2008;3(01):1–11
25 Tinker SC, Moe CL, Klein M, et al. Drinking water turbidity and emergency department visits for gastrointestinal illness in Atlanta, 1993-2004. J Expo Sci Environ Epidemiol 2010;20(01):19–28
26 Hu R, Feng J, Hu D, et al. A rapid aqueous fluoride ion sensor with dual output modes. Angew Chem Int Ed Engl 2010;49(29): 4915–4918
27 Asadi SS, Vuppala P, Reddy MA. Remote sensing and GIS techniques for evaluation of groundwater quality in municipal corporation of Hyderabad (Zone-V), India. Int J Environ Res Public Health 2007;4(01):45–52
28 Armienta MA, Segovia N. Arsenic and fluoride in the groundwater of Mexico. Environ Geochem Health 2008;30(04): 345–353
29 Chakraborti D, Das B, Rahman MM, et al. Status of groundwater arsenic contamination in the state of West Bengal, India: a 20-year study report. Mol Nutr Food Res 2009;53(05):542–551
30 Janardhana Raju N, Shukla UK, Ram P. Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. Environ Monit Assess 2011;173(1-4):279–300

