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GROUNDWATER QUALITY INDEX OF CHANDRAPUR DISTRICT, CENTRAL INDIA

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Abstract

Groundwater is the primary source of drinking water in Chandrapur district, Central India; however, rapid industrialization, coal mining, and urban expansion have raised serious concerns regarding its quality. The present study evaluates the groundwater quality of Chandrapur district using the Water Quality Index (WQI) approach to provide an integrated assessment of its suitability for drinking purposes. A total of 36 groundwater samples were collected during the post-monsoon season from hand pumps and dug wells across different sub-districts of the district. Physicochemical parameters, including pH, total dissolved solids (TDS), chloride, alkalinity, total hardness, fluoride, arsenic, iron, and manganese, were analyzed following standard methods as described in American Public Health Association (APHA), and WQI values were computed using weighted arithmetic index methodology. The calculated WQI values ranged from 85 to 874, indicating wide spatial variability in groundwater quality. Only two samples (5.55%) were classified as good quality water, while the majority fell into poor (63.88%), very poor (25.00%), and unsuitable (5.55%) categories. Elevated concentrations of TDS, hardness, fluoride, arsenic, iron, and manganese were identified as the major contributors to groundwater quality deterioration. The dominance of poor to unsuitable groundwater quality reflects the combined influence of shallow aquifer conditions, favourable permeability, intensive mining and industrial activities, and surface-derived contamination. The results reveal that more than 94% of groundwater sources in the district are unsuitable for direct human consumption without treatment. The study highlights the urgent need for regular groundwater monitoring, implementation of appropriate treatment technologies, and strengthened regulation of industrial effluents. The WQI-based assessment provides a valuable decision-support tool for sustainable groundwater management and public health protection in Chandrapur district.

Keywords: *Groundwater quality, Water quality index, Chandrapur, Central India*

Introduction

Freshwater resources are essential for sustaining human health, economic development, and ecological integrity. However, rapid urbanization, industrial growth, agricultural intensification, and population expansion have resulted in significant degradation of both surface and groundwater quality worldwide (UNESCO, 2020). In developing countries, inadequate wastewater treatment infrastructure and unregulated discharge of industrial and domestic effluents further aggravate water quality deterioration, posing serious risks to public health and aquatic ecosystems (WHO, 2017). Consequently, comprehensive assessment and continuous monitoring of water quality have become imperative for sustainable water resource management.

Water quality is typically evaluated using a wide range of physicochemical and biological parameters, such as pH, dissolved oxygen, total dissolved solids, nutrients, and hardness. Although analysis of individual parameters provides detailed information, it often fails to present an integrated picture of overall water quality that is easily interpretable by decision-makers and the public (Horton, 1965). To overcome this limitation, the Water Quality Index (WQI) was developed as a numerical tool that aggregates multiple water quality parameters into a single dimensionless value, reflecting the overall status of water quality for a specific use (Brown *et al*., 1970).

The WQI approach simplifies complex datasets and facilitates spatial and temporal comparison of water quality across different regions and time periods. It has been widely applied in the assessment of rivers, lakes, reservoirs, and groundwater systems under diverse hydrogeological and land-use conditions (Sutadian *et al*., 2016). By identifying pollution hotspots and long-term trends, WQI serves as an effective decision-support tool for environmental planning, pollution control, and resource management. Despite certain limitations related to parameter selection and weighting, WQI remains one of the most widely accepted methods for preliminary water quality evaluation and communication (Tyagi *et al*., 2013).

In the context of increasing anthropogenic stress on freshwater resources, particularly in rapidly developing regions, the application of WQI provides valuable insights into cumulative water quality impacts. The present study utilizes the WQI framework to assess the overall water quality status of the study area, examine spatial variability in key physicochemical parameters, and evaluate the suitability of water for intended uses. The results are expected to contribute to informed decision-making and the formulation of effective strategies for sustainable water resource management.

The WQI is a widely recognized tool that consolidates multiple physicochemical parameters into a single metric, facilitating comparison across locations and time, and assisting stakeholders in decision-making regarding water resource management (Environmental Studies Institute, 2024). In the context of Chandrapur, WQI applications can elucidate temporal and spatial trends in water quality, identify pollution hotspots, and support targeted interventions by policymakers and local authorities. This study thus aims to evaluate the water quality status of key freshwater sources in Chandrapur district using the WQI framework, interpret the influence of anthropogenic pressures, and propose evidence-based recommendations for sustainable water management.

Study Area

The Chandrapur district (19°25' to 20°45' N and 78°50' to 80°10' E), which lies in the Vidarbha area of Maharashtra state in central India is 11,364 square kilometres in size and ranges in elevation from 106 to 589 meters above mean sea level. The district is divided into 15 sub-districts (Fig. 1). Along with dense forests and wildlife, the region is rich in natural resources, such as coal, limestone, iron, copper, and other minerals. Because of the region's wealth in minerals and natural resources, it has seen the construction of numerous thermal power plants, cement factories, pulp and paper mills, and massive coal mines. The district also has Tadoba Andhari Tiger Reserve, which has one of the largest numbers of tigers in the world (CGWB, 2009).

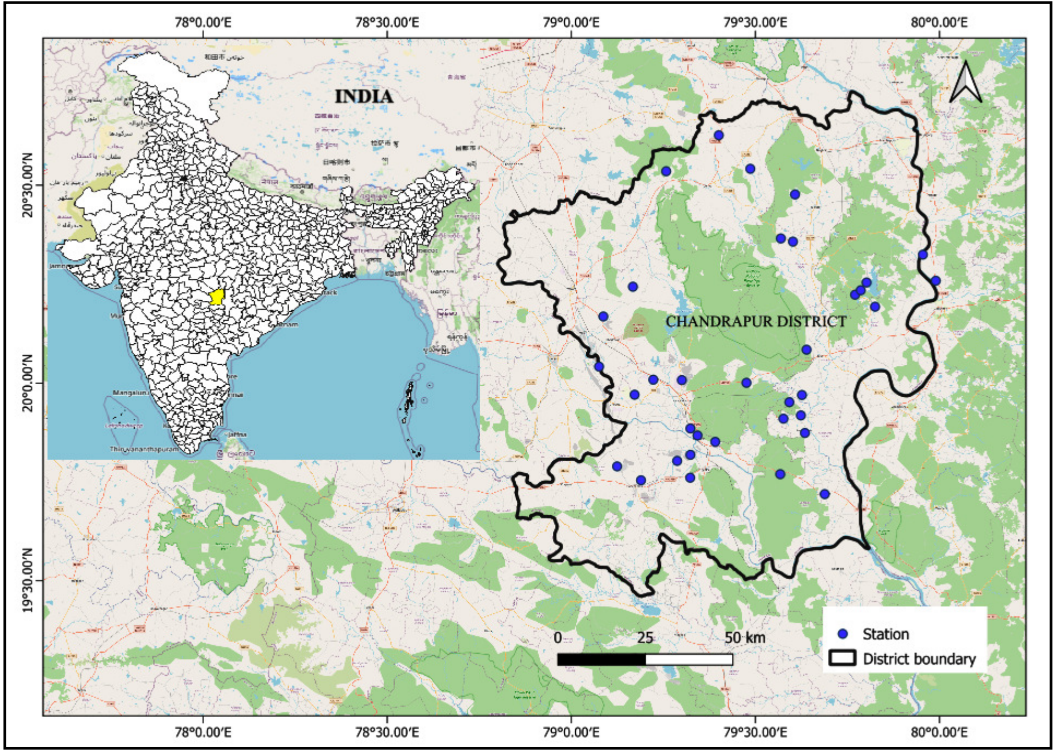

Fig. 1: Spatial distribution of groundwater sampling locations in the study area

In addition to year-round general aridity, the district has a range of climatic extremes, such as a hot summer (May, with highs of 46ºC) and a cold winter (December, with lows of 7ºC). The climate of the area could be described as tropically hot. The humidity was recorded at 70% during the monsoon and 20% during the summer. Rainfall from the southwest monsoon occurred throughout the rainy season (June to September), with an average of 60 to 65 wet days per year and an annual rainfall range of 1200 to 1450 mm. Rainfall is distributed unevenly throughout the district. The Worora administrative block experiences relatively little rainfall, which gradually rises to a maximum close to the Bramhapuri administrative block (CGWB, 2009) (Fig. 2). According to geology, the Chandrapur district is part of the Gondwana sedimentary basin. The lithology of the Chandrapur region is varied, ranging from the Archean to more recent alluvium and laterites.

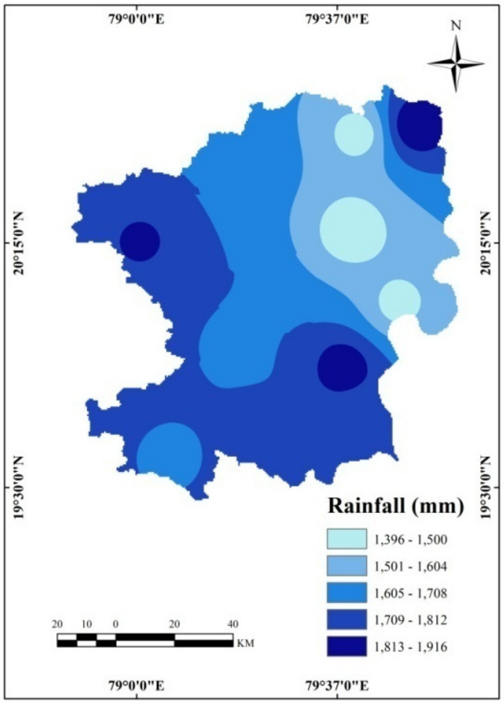

Fig. 2: Spatial distribution of precipitation in the study area

A total of 10,73,946 women and 11,20,316 men make up the district's 21,94,262 inhabitants, according to the 2011 Census of India. According to reports, the population density was 192 people per square kilometre, the decadal growth rate from 2001 to 2011 was 6.0%, and 35.1% of people lived in urban areas. A detailed examination of census data reveals that 43.2% of the population's primary source of drinking water in the rural areas of the Chandrapur district comes from tube wells and hand pumps (36% and 7.2%, respectively). This statistical data indicates that groundwater is the primary source of drinking water for people living in the study area (Census of India, 2011).

Material and Methodology

Groundwater Sampling

The groundwater sample site selection criteria gave priority to the rural portion of the study region due to its heavy reliance on hand pumps and/or dug wells for domestic requirements such as cooking and drinking. Groundwater samples were also obtained from a number of sub-districts in the district, which include a range of geological formations, precipitation classes, and altitudes, to better understand the WQI. In the post-monsoon season, in October, the groundwater samples were collected.

For this study from the Chandrapur district, a total of 36 groundwater sampling locations were selected. The sampling locations on different elevations from the study area are depicted in Fig. 3 which includes hand pumps and dug wells. Stratified and deliberate random sampling was employed for the groundwater sample from the study area. Two sampling sites (5.55%) were from dug wells, whereas 34 (94.44%) were from hand pumps. Groundwater samples were collected using the grab sampling method.

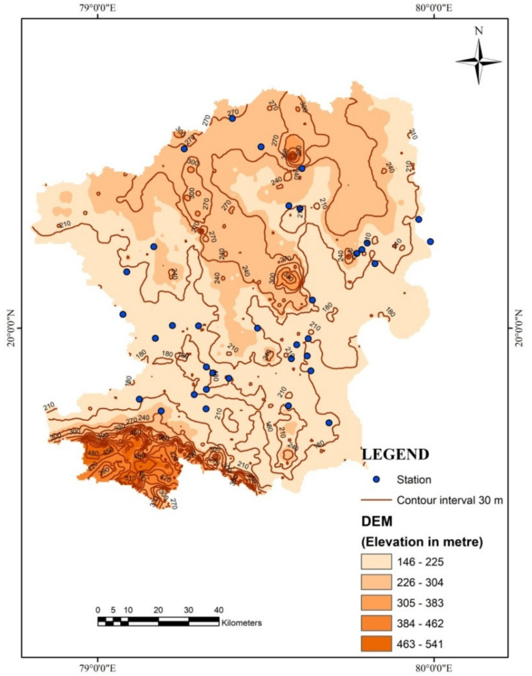

Fig. 3: Groundwater sampling locations from different elevations

The groundwater sample was extracted up to the edge of a 1000 mL capacity polyethylene container (Poly lab, India) to prevent headroom that can change the sample's physicochemical characteristics. This was carried out to determine the general properties of the groundwater sample. To keep contaminants out, the sampling containers were closed with packing tape after being secured with a screw cover. The details about sampling locations were recorded in the field diary and on the sampling container. With the use of a handheld GPS, the geographic information related to latitude, longitude, and altitude was gathered.

Groundwater Analysis

The temperature of groundwater fluctuates when it is exposed to the atmosphere, so the data it gives in the field is accurate. A mercury thermometer (Gera, GTI, India) with a 0.5 ^{o}C division was used to measure it on the spot. The different physicochemical properties were checked for in the laboratory on the groundwater samples, with the exception of the field analysis parameter. For the physicochemical analysis, borosilicate glassware was used, and all of the reagents were analytical reagent grade (Merck). The reagents were prepared using double-distilled water. According to APHA recommendations, all reagents were prepared. These reagents underwent a standardization process before being utilized for analysis. Groundwater samples were transported to the laboratory and analyzed for various physicochemical parameters following the standard procedures prescribed by APHA (APHA, 2017).

The heavy metal (in this case, arsenic, iron and manganese) present in the groundwater samples was preserved by adding concentrated nitric acid (HNO_3, 16 N, Merck, 1 mL per 100 mL of sample) on-site to another polyethylene container (Poly lab, India). The entry of contaminants in the sampling container was arrested by closing the container with a screw cap followed by an adhesive tape. The groundwater samples were promptly taken to the laboratory to analyze the levels of heavy metals concentration.

Groundwater samples were digested to determine arsenic, iron and manganese content using concentrated nitric acid (HNO_3). Approximately 50 mL of each sample was placed in pre-leached glass beakers, covered with clean watch glasses, and heated on a hot plate at 95 °C until reduced to ~5 mL without boiling. After cooling, 1:1 nitric acid (16 N, Merck) was added, and the samples were refluxed for 15 minutes to dissolve any precipitates. The digests were cooled, diluted to 25 mL with double-distilled water in volumetric flasks, and used for analysis. The heavy metals concentrations were measured by using Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES; PerkinElmer Optima Dv 7000, Shelton, CT, USA) with WinLab 32 for ICP software (version 4.0). Analysis was performed by using axial plasma view. A low-flow GenCone nebulizer and cyclonic spray chamber were used for sample introduction. Calibration was performed using working standards prepared from a NIST traceable PerkinElmer stock standard. All solutions were prepared with double-distilled water and matrix-matched to ensure analytical accuracy.

Quality Control / Quality Assurance

To ensure quality control, the glassware used in reagent preparation and analysis was cleansed with nitric acid (HNO_3, 15%, Merck) and then washed three times with distilled water. The reagents used in the analysis were all of analytical reagent grade. Furthermore, the various instruments used in groundwater analysis were calibrated as per standard procedure and maintained to provide accurate and precise measurements. The standard methods as described in APHA (2017) were followed to ensure consistency and compatibility of results. The certified reference materials were used for accuracy and to detect potential biases. A groundwater sample was analysed three times for a particular parameter for precision and reproducibility of the results. The blank analysis was carried out—wherever required—to assess the presence of contaminants in the analytical process itself. The sample injection system of the ICP consists of a spray chamber with a temperature-controlled nebulizer connected to an auto-sampler. Throughout the measurement period, consistent operating conditions were maintained which resulted in maintained ICP responsiveness. The reporting was carried out with a 95% level of confidence to ensure repeatability for all samples prepared, analysed, and results. The findings of laboratory analysis were overlapped to validate the inverse distance weighting (IDW) interpolation results. The IDW interpolation map's pixel values closely correspond to the field verification data.

Results and Discussion

Groundwater Quality Index

The WQI technique can quantitatively assess and compare the degree of pollution of various water quality metrics in addition to providing a comprehensive expression of groundwater quality information (Sahu and Sikdar, 2008). This index is a tool in mathematics that is used to convert a sizable amount of data on the characterisation of the water into a single figure that represents the water quality level (Sanchez *et al.* 2007). First, a weight (wi) was assigned to each chemical characteristic based on how it affected groundwater quality and human health. Due to their significant significance in the evaluation of water quality, the parameters such as total dissolved solids, total hardness, fluoride, arsenic, iron, and manganese were given the highest weight of 5 in this study. When these characteristics exceed critical concentration limits, they can have detrimental impacts on health and reduce the amount of groundwater that can be used for residential and drinking reasons (Sener *et al.* 2017; Yidana and Yidana, 2010). Other various weights were applied to the parameters, which ranged from 2 to 4. The following formula is used to calculate the relative weight

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

where n is the number of parameters, wi is the weight of each parameter, and Wi is the relative weight [Eq. (1)].

The quality rating for each parameter is then calculated by dividing the concentration of the parameter in each water sample by the Indian standard and multiplying the result by 100.

$$\mathrm{qi} = \frac{\mathrm{Ci}}{\mathrm{Si}} \times 100 \qquad (2)$$

where Ci is the concentration of each characteristic in each water sample and qi is the quality rating [Eq. (2)]. For every characteristic established by the Indian national standard, Si is the drinking water standard.

To calculate the WQI, the SIi was determined firstly

$$\mathrm{SIi} = \mathrm{Wi} \times \mathrm{qi}$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SIi} \qquad (3)$$

where SIi is the ith parameter's sub-index [Eq. (3)]. The WQI values are classified into five categories: excellent water (less than 50), good water (between 50 and 100), poor water (ranging from 100 to 200), very poor water (from 200 to 300), and unsuitable water (greater than 300) (Sahu and Sikdar, 2008).

Water Quality Index

Using the previously described WQI, the following parameters are chosen for this study in order to assess the overall quality of the groundwater: pH, Cl^-, TDS, alkalinity, total hardness, fluoride, arsenic, iron, and manganese. Since electrical conductivity has no Indian drinking water standard, its values were not taken into account in the study. Although they have a minor effect on water quality, temperature, calcium hardness, and magnesium hardness are not taken into consideration when evaluating WQI. Table 1 displays the weightage and relative weightage given to each parameter.

Table 1: Relative weightage of hydro-chemical parameters

Parameter	Indian Standard	Weightage (wi)	Relative weightage (Wi)
pH	6.5-8.5	4	0.1053
TDS	500	5	0.1316
Chloride	250	2	0.0526
Alkalinity (Total)	200	2	0.0526
Hardness (Total)	200	5	0.1316
Fluoride	1.0-1.5	5	0.1316
Arsenic	0.01	5	0.1316
Iron	0.3	5	0.1316
Manganese	0.1	5	0.1316
		∑wi = 38	∑Wi = 1.0000

All measurements are presented in milligrams per litre (mg/L), with the exception of pH, which is expressed as a dimensionless value

The WQI values calculated for groundwater sources across Chandrapur district reveal substantial spatial variation in groundwater quality (Table 2). The WQI values range from 85 (Lohara, HP) to 874 (Dabgaon Tukum, HP), indicating water quality conditions varying from good *to* unsuitable for drinking purposes. Based on standard WQI classification criteria, groundwater samples were categorized into four classes: good (WQI < 100), poor (100–200), very poor (200–300), and unsuitable (>300).

Table 2: WQI values and classifications of water quality status in the study area

Sampling location (Groundwater source)	WQI	Water quality status
Sonegaon (HP)	105	Poor water
Telwasa (HP)	129	Poor water
Belora (HP)	137	Poor water
Sagra (DW)	168	Poor water
Pethbhansouli (HP)	152	Poor water
Bhisi (HP)	396	Unsuitable water
Pimpalgaon (HP)	231	Very poor water
Mowada (HP)	122	Poor water
Dongargaon (HP)	205	Very poor water
Lohara (HP)	85	Good
Chichpalli (HP)	291	Very poor water
Dabgaon (Tukum) (HP)	874	Unsuitable water
Naleshwar (HP)	158	Poor water
Karwan (HP)	125	Poor water
Chikmara (HP)	155	Poor water
Pathri (HP)	111	Poor water
Gunjewahi (DW)	90	Good
Mangali Chak (HP)	107	Poor water
Govindpur (HP)	178	Poor water
Ratnapur (HP)	217	Very poor water
Antargaon (HP)	117	Poor water
Visapur (HP)	276	Very poor water
Ballarpur (HP)	257	Very poor water
Sasti (HP)	247	Very poor water
Gowari (HP)	133	Poor water
Arvi (HP)	119	Poor water
Awarpur (HP)	150	Poor water
Lakhmapur (HP)	113	Poor water
Kem (Tukum) (HP)	153	Poor water
Ganpur (HP)	247	Very poor water
Gondpipari (HP)	178	Poor water
Pombhurna (HP)	160	Poor water
Jam Tukum (HP)	159	Poor water
Dongar Haldi (HP)	186	Poor water
Durgapur (HP)	212	Very poor water
Morwa (HP)	149	Poor water

HP – Hand Pump, DW – Dug Well, WQI – Water Quality Index

Only two locations, Lohara (WQI = 85) and Gunjewahi (WQI = 90), fall within the good water quality category, accounting for a very small proportion (5.55%) of the total sampling sites. A majority of the groundwater samples (n = 23, 63.88%) exhibit poor water quality (WQI 100–200). These results indicate moderate contamination of groundwater sources across much of the district.

A significant number of sampling locations (n=10, 25%) fall into the very poor water quality category (WQI 200–300). Groundwater from these locations is unsuitable for direct consumption and requires substantial treatment prior to use.

Extremely high WQI values were recorded at Bhisi (WQI = 396) and Dabgaon (Tukum) (WQI = 874), categorizing these sites as unsuitable for drinking. Such elevated WQI values indicate severe groundwater contamination and pose serious risks to human health. The majority of these highly contaminated sources are hand pumps, suggesting greater vulnerability of shallow aquifers to surface-derived pollutants. Overall, the WQI distribution reveals that over 94% (n=34) of groundwater samples fall into poor, very poor, or unsuitable categories, highlighting widespread groundwater quality degradation across the district. These findings emphasize the urgent need for regular monitoring, source protection, and implementation of effective groundwater management and treatment strategies in Chandrapur district. The widespread deterioration of groundwater quality underscores the influence of anthropogenic activities such as mining, industrial operations, urbanization, and improper waste disposal, highlighting the need for regular monitoring and effective groundwater management strategies.

Table 3: Water Quality Index summary

Water Quality Index	n (%)
Excellent water (< 50)	Nil
Good water (51-100)	2 (5.55%)
Poor water (101-200)	23 (63.88%)
Very poor water (201-300)	9 (25.00%)
Unsuitable water (> 300)	2 (5.55%)

According to the WQI assessment results, poor water (WQI 101-200) (Fig. 4) dominates (63.88%) the groundwater in the study region and is broadly distributed throughout the study area, except the southeast. Arsenic, iron, manganese, fluoride, hardness, and TDS are the primary groundwater contaminants in this region; the majority of these levels are higher above the upper limit of Indian drinking water guidelines. The buried depth of groundwater may be a contributing factor to the study area's low groundwater quality. In general, surface pollutants take longer to reach the aquifer when the groundwater is sunk deeper. The level of groundwater system contamination will therefore decline as a result of the increased likelihood that the contaminants will be adsorbed and diluted throughout the infiltration process. In most places, the district's groundwater depth is just 10 meters below ground level (bgl), but in some places, it can reach deeper depths of 10 to 20 meters. With a minimum of 0.95 m bgl, Rajoli Tukum, during the post-monsoon season and a maximum of 18.62 m bgl, Bhandak, during the summer, the seasonal influence on the groundwater depth was noted (CGWB, 2009). Furthermore, the district's soils are shallow coarse, medium black, and deep black, and they respond somewhat alkaline. Groundwater contamination results from surface pollutants more easily penetrating the groundwater due to the aquifer's improved permeability.

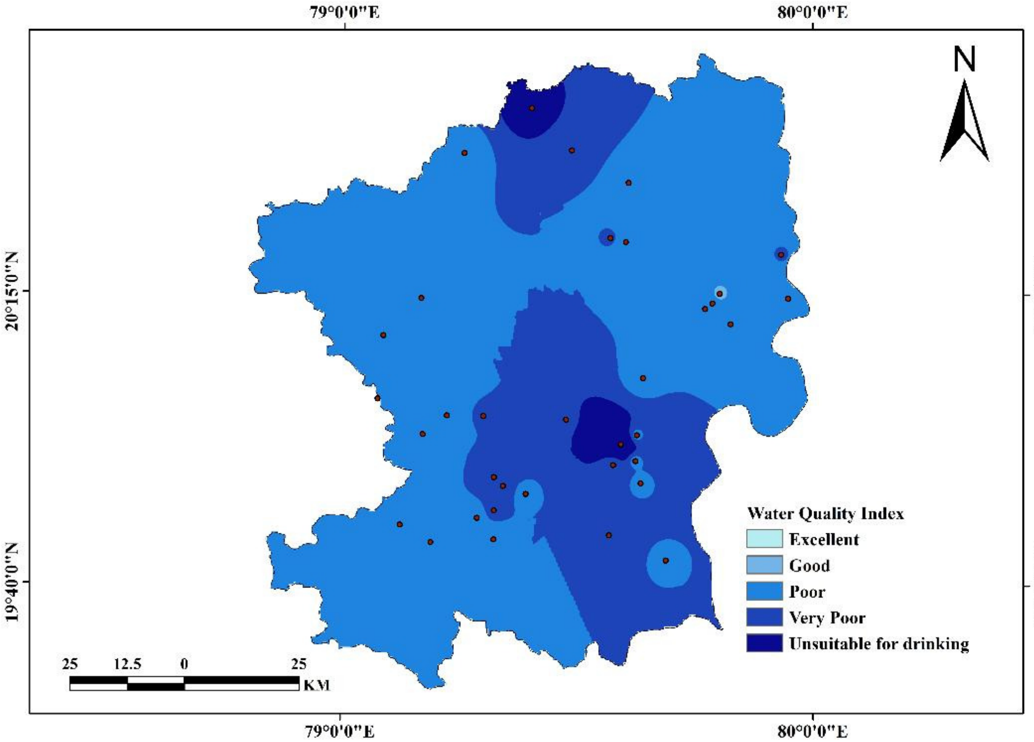

Fig. 4: Groundwater quality distribution according to water quality index values

Coal and metal deposits, especially iron ore, contribute to the presence of iron and manganese in groundwater. Increased levels of iron and manganese can dissolve in groundwater when the ionic strength is higher and the activity coefficient is lower, which is often a result of elevated total dissolved solids. Furthermore, the dissolved oxygen in groundwater can be rapidly depleted by the organic matter discharged by surface pollution, establishing an environment for reductive hydrochemistry that is more favourable for the breakdown of iron and manganese (Zhang *et al*., 2020).

Accordingly, the findings of the study it shows that the majority of the study area's groundwater is unfit for human consumption. Together, the 34 (94.44%) sampling sites from the poor (n = 23), very poor (n = 9), and unsuitable water (n = 2) quality index status highlight the importance of implementing safe water supply measures at the earliest and the deployment of groundwater pollution remediation technology.

In the Anantapur district of Andhra Pradesh, groundwater WQI values in rural areas predominantly indicated *poor* quality, with the majority of samples falling within the 100–200 WQI range, and only a minority classified as *good* water (WQI < 100) (Ambiga, 2025). In this study, about 87% of the sampling area was reported in the poor water category—a proportion similar to the 63.88% poor category observed in Chandrapur—highlighting comparable groundwater quality challenges in drought-prone and agriculturally stressed regions of southern India.

Groundwater quality evaluations from other parts of India also show significant water quality degradation. In the Kulpahar watershed, Mahoba district (Uttar Pradesh)**,** WQI values ranged up to 115.93 with poor to unsuitable groundwater zones identified, particularly in southern blocks, indicating localized pockets of heavily compromised water quality (Ram *et al*., 2023). Here, although some areas exhibited WQI values within *excellent* or *good* categories, a notable portion of the region exhibited *poor* to *unsuitable* conditions, mirroring the overall trend observed in Chandrapur where only a small fraction of sites had good water quality.

In the Bokaro district of Jharkhand, pre-monsoon WQI values ranged from approximately 55 to over 228, with average values indicating *poor* quality for many sampling points (Verma *et al*., 2020). This range overlaps with the WQI classes identified in Chandrapur, especially in the *poor* and *very poor* categories, reflecting how industrially influenced hydro-geological settings often exhibit elevated WQI values due to increased concentrations of dissolved solids and associated pollutants.

Comparative studies in Agra district (Uttar Pradesh) similarly reveal that both urban and rural groundwater sources largely fall into the *unfit* and *poor* categories due to geogenic and anthropogenic influences, indicating that groundwater quality challenges are not restricted to any single hydro-climatic zone but are widespread across diverse Indian environments (Ali, 2024).

Taken together, these comparative studies illustrate that the poor to very poor and unsuitable groundwater quality observed in Chandrapur district aligns with a wider pattern of degraded WQI status across multiple Indian regions. While the specific causes of contamination vary—from irrigation and fertilizer leaching in Andhra Pradesh and Uttar Pradesh to mining and industrial effluents in Jharkhand and Maharashtra—the resulting decline in water quality underscores the pressing need for improved groundwater management, pollution control strategies, and targeted remediation efforts at both local and regional scales.

Conclusion

The present study provides a comprehensive evaluation of groundwater quality in Chandrapur district, Central India, using the WQI approach. The computed WQI values ranged from 85 to 874, indicating substantial spatial variability in groundwater quality. Only 5.55% of the sampled locations were classified as having good water quality, while the remaining 94.44% fell within poor, very poor, or unsuitable categories, rendering the majority of groundwater sources unfit for direct human consumption.

The elevated WQI values are primarily attributed to high concentrations of total dissolved solids, hardness, fluoride, arsenic, iron, and manganese, which exceed permissible drinking water limits in several locations. Shallow groundwater depths, favourable aquifer permeability, intensive coal mining, industrial activities, and improper waste disposal practices have collectively contributed to groundwater quality deterioration in the district.

Comparative analysis with other Indian districts confirms that the groundwater quality degradation observed in Chandrapur reflects a broader national issue. However, the presence of extreme WQI values (>300) at certain locations indicates localized zones of severe contamination that require immediate intervention. The findings highlight the urgent need for regular groundwater monitoring, implementation of appropriate treatment technologies, stricter regulation of industrial effluents, and development of alternative safe drinking water sources**.**

The WQI-based assessment presented in this study serves as an effective decision-support tool for water resource managers and policymakers. The results can aid in prioritizing remediation measures and formulating sustainable groundwater management strategies to safeguard public health in Chandrapur district.

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