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Groundwater Quality Analysis for Wardha, Maharashtra, India

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ABSTRACT

Arid and semi-arid regions significantly depend upon groundwater to meet their water demand, especially when groundwater is the only and limited resource for drinking and other human needs. The primary concerns are the excessive consumption of groundwater for agricultural and industrial activities, low recharge rate and percolation of impurities in groundwater, affecting groundwater quality and quantity. This study was performed to identify the variation in the water quality of groundwater of arid or semi-arid regions using geographical information system (GIS) and water-quality index (WQI). The database generated by analyzing samples of 3 decades (1990 to 2019) spatially varied over 68 sampling locations and the dataset was classified based on designated use. The dispersal of chemical constituents in groundwater over the study area was determined using GIS and water quality was classified based on WQI. The maximum concentrations of magnesium, nitrates and sulphates were found to be 307.6 mg/L, 600.16 mg/L and 890.0 mg/L, respectively, but the overall water quality was found varying between marginal and good due to tremendous variations. The southeastern and southwestern parts of the study area were found to be majorly affected with high concentrations of electrical conductivity, total hardness, chlorides and sulphates. Integrating GIS and WQI gives new knowledge on the spatial variation in groundwater characteristics for designated use. The integrated model derives valuable information for land-use planners and decision-makers on groundwater-resource management.

KEYWORDS: Groundwater, Groundwater-quality index, GIS, Spatial distribution.

INTRODUCTION

The ever-increasing population of India raised tremendous pressure on various resources of the country (Ray and Ray, 2011). The conversion of rural areas into urban areas and industrialization in multiple parts of the country further increase the load over the surface and groundwater resources (Khatri and Tyagi, 2015). The excessive usage of groundwater in agricultural activities, industrial purposes and domestic supply in the absence of surface-water sources exerts extensive pressure on groundwater resources (Kumar et al., 2013; Ravi et al., 2020).The percolation of industrial effluent, agricultural run-off and dissolved impurities from untreated sewage into groundwater raises serious health concerns, as a large part of the community in India consumes groundwater either without or after primary treatment (Goitsemang et al.,2020). The physio-chemical interaction and dynamic behaviors of various impurities necessitate the characterization of groundwater resources before water usage for any purpose or restoration of groundwater quality. The Central Groundwater Board (CGWB) recommends monitoring groundwater resources to identify the ongoing and emerging problems and contamination levels of groundwater in compliance with drinking-water standards (CGWB, 2018). Monitoring and assessing groundwater quality at critical locations provide valuable information for developing and allocating consumptive-usage plans for groundwater (Knüppe, 2011; Pande et al., 2020; Arora and Keshari, 2021).

The advent of geographical information systems (GISs), which involve utilizing large satellite-based raster or vector data for the analysis, has reduced the efforts and

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time required to interpret extensive field studies. The data obtained during the conventional field analysis technique can be analyzed using GIS tools for large catchment areas and data could also be obtained from inaccessible locations using satellite data (Sadat-Noori et al., 2014; Rawat and Singh, 2018; Dandge and Patil, 2022; Sunitha and Reddy, 2022; Hosseininia and Hassanzadeh, 2023). Information on land use/land cover (LULC) could provide access to development concerning new industrial activities or setting up a new habitat or town, converting land type from agricultural to industrial or from forest to agricultural. Regularly monitoring satellite images could provide LULC data that is further analyzed using GIS techniques. The allocation of sampling data points on GIS tools has reduced the efforts of researching and comparing different stations spatially and temporally (Omar et al., 2020; Sunitha and Reddy, 2022; Hosseininia and Hassanzadeh, 2023). The interpolation method successfully identifies groundwater quality along large areas and the spatial distribution of groundwater characteristics (Machiwal et al., 2018; Dandge and Patil, 2022). The water-quality index (WQI) is used prominently to determine water quality for various purposes (Fang et al., 2020). Researchers have applied different methods for the development of WQI to determine the relative weight of water-quality parameters in producing variation in overall characteristics (Lumb et al., 2011; Poonam et al., 2013; Şener et al., 2017; Subba Rao et al., 2018; Akhtar et al., 2013).

Subba Rao et al. (2018) applied the water-quality index for groundwater to determine the contamination level in water quality in Telangana, India. Kawo and Karuppannan (2018) used the GIS technique to quantify the spatial variation of major cations and anions and applied WQI to identify the applicability of groundwater resources for specific purposes. Duraisamy et al. (2019) studied physio-chemical parameters to assess groundwater quality using GIS. Bawoke and Anteneh (2020) applied statistical arithmetic techniques to quantify the weight of various water-quality parameters and provided a rating for each parameter to generate WQI. Fang et al. (2020) integrated multivariate statistical techniques with GIS and WQI to quantify the periodic variations in the concentrations of water-quality parameters and demonstrated the spatial distribution of parameters. Ram et al. (2021) performed the spatial analysis of chemical constituents of groundwater and derived the WQI to identify the area concerned with degraded water quality. Singh and Noori (2022) determined the spatial distribution of groundwater characteristics utilizing GIS tools and WQI and assessed the potential of different anions and cations to affect water quality. Vaiphei et al. (2020) determined the dominant cations, anions and hydro-chemical facies affecting water quality and developed WQI to evaluate the overall water quality using GIS techniques. Alemu et al. (2022) simulated groundwater quality using WQI to identify the designated use of groundwater. Khafaji et al. (2022) developed the WQI for irrigation activity through an overlay approach and performed spatial distribution using GIS in four classes. The successful application of WQI for different geographical conditions suggests the broader area of application of WQI for the prediction of water quality; however, the adequacy of WQI was rarely validated (Ravichandran, 2023).

The research gap observed in the previous studies is that the research outcome was focused towards quantification of water-quality characteristics and development of WQI, but less focus was given to sources of pollution and identification of designated use of groundwater. Groundwater is available in the unconfined aquifers in the Wardha district of Maharashtra and is considerably used for agricultural practices (CGWB, 2021). The study was carried out with backtracking of pollutants and identification of pollution sources. This study was performed with the objectives to 1) determine the multi-dimensional variability of physio-chemical constituents to assess the level of impact of anthropogenic activities and 2) to determine the applicability of groundwater for drinking and agricultural activities. The backtracking of pollutants is performed in this study for the first time to determine the sources of pollutants. The geographical distribution and anthropogenic activities are traced to identify the emerging points of pollutants. The study's objectives would assist policymakers and planners in evaluating the potential use of groundwater to minimize the health risk due to contamination of groundwater (Kalhor et al., 2019; Ravindra et al., 2019). The proposed methodology could be applied to any aquifers in arid or semi-arid regions, receiving effluents from multiple sources.

MATERIALS

Study Area

The area under consideration is in the Wardha district of Maharashtra, India, as shown in Figure 1, developed using ArcGIS. Wardha river is a sub-basin of Godavari basin, lying in the latitudinal range of 19°18'N and 21°58'N and the longitudinal range of 77°20'E and 79°45'E. The Wardha river originates in the Satpuda range of Madhya Pradesh in Betul district. Wardha river majorly flows in Maharashtra after traveling 32 km in Madhya Pradesh, having a watershed area of 48,000 km^2 up to its confluence in Wainganga river. The Wardha river travels from north to west in the Wardha district of Maharashtra and joins the Wainganga river at the north in the Chandrapur district of Maharashtra to form the Pranhita river, which is a significant tributary of Godavari river. Wardha district of Maharashtra contains black soil over the pile of rock generated from the volcanic trap (CGWB, 2021).

The annual mean precipitation of Wardha district is around 1058 mm, spread over 47 to 50 days. The isohyetal map of rain is shown in Figure 2 (CGWB, 2021). The precipitation data of the study area was attained from the Indian Meteorological Department (IMD) for 2020 to develop the isohyetal maps. Precipitation is the primary water source for groundwater recharge received during monsoon, whereas, for the rest of the year (lean period), groundwater is used for irrigation and other activities. The discharge of wastewater from point sources (commercial, industrial and residential areas) and non-point sources contaminate groundwater as well as surface-water sources. The abstraction of groundwater for agricultural and other activities and variations in annual precipitation affect the groundwater level significantly (Mithani et al., 2012). The groundwater level varies considerably between 0.15 m and 11.5 m, as shown in Figure 3 (CGWB, 2021). The northern part of the district observes significant fluctuations in water level compared to the southern region.

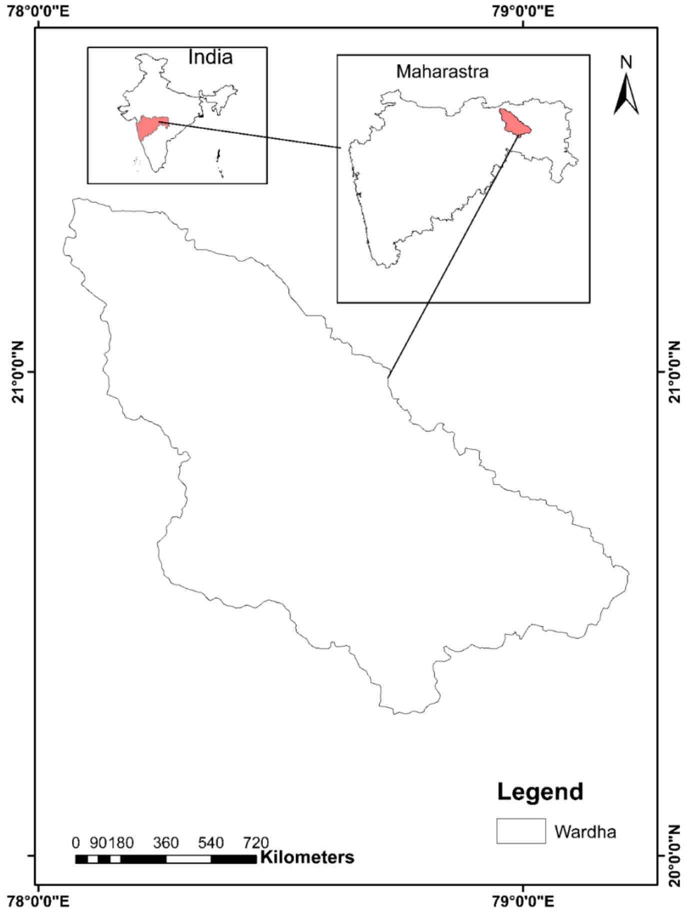

Figure (1): Study area of Wardha district, sub-basin of Godavari river basin

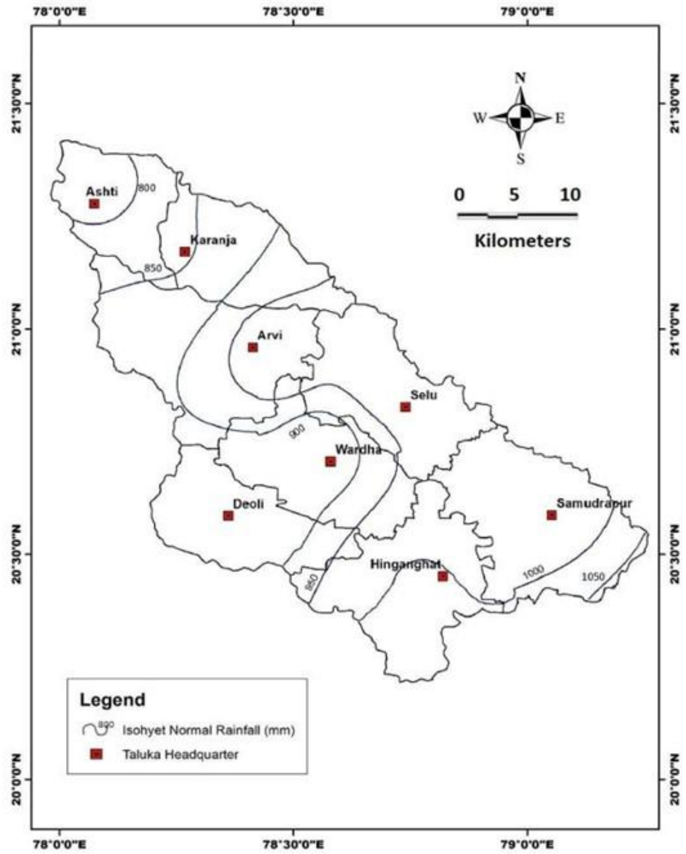

Figure (2): Isohyet line of Wardha district, Maharashtra (CGWB, 2021)

Data Collection

The study area comprises 68 sampling sites (dug wells) in 61 villages and 9 tehsils of the Wardha district of Maharashtra. The database of groundwater samples was developed using dug-well analysis of the Central Ground Water Board (CGWB) maintained for nearly three decades (1990-2019). 893 groundwater samples were analyzed and collected from 68 sampling locations. The CGWB performed the analysis of water samples following the standard operating procedure as prescribed by the Bureau of Indian Standards (BIS) 10500:2012 (BIS, 2012) and adopted adequate sample-preservation guidelines (CGWB, 2021) and every sample was analyzed for different parameters. The water-quality parameters and salts including pH, total hardness (TH), total dissolved solids (TDS), electrical conductivity (EC), total alkalinity, calcium, magnesium, sodium, potassium, carbonates, bicarbonates, chlorides, sulphites, fluorides and nitrates were evaluated from each groundwater sample.

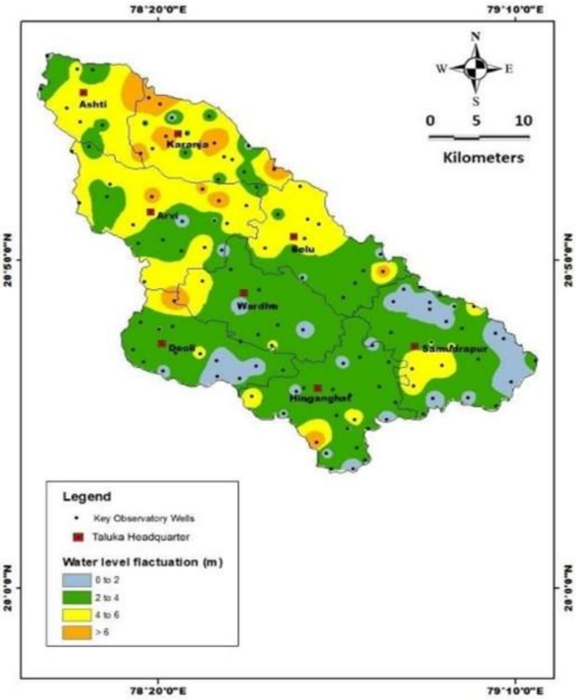

Figure (3): Water-level fluctuations in Wardha district, Maharashtra (CGWB, 2021)

METHODOLOGY

Groundwater-data Analysis

The location of each sampling location is identified using geotagging. The spatial variability of parameters was determined using statistical analysis and the GIS technique. The spatially distributed maps of the study area were derived from Inverse Distance Weighting (IDW) in ArcGIS 10.8 version, which is an interpolation method for filing data gaps, as discussed below for each parameter. The variation of each parameter throughout the study period is also assessed using box-whisker plots (Banacos, 2011).

Groundwater-quality Index (GWQI)

The GWQI was developed for the study area using the Bureau of Indian Standards (BIS) water-quality standards for drinking water. The GWQI was applied to reduce the multi-variate nature of water-quality parameters and the dynamic variability of different parameters. The procedure of CCME WQI (2001) was adopted to develop the GWQI for the study area based on total parameters exceeding the discharge limits, total number of samples exceeding the limits and amplitude of variation about standard value (Hurley et al., 2012). The three factors are determined to develop index values for scope, frequency and amplitude, defined as F1, F2 and F3, respectively. F1 and F2 are shown in Equations 1 and 2 and F3 is shown in Equation 5 (CCME, 2001).

$$F_1 = \frac{Parameters\ exceeding\ the\ standard\ values}{Total\ number\ of\ parameters} * 100 \quad (1)$$

$$F_2 = \frac{Samples\ exceeding\ the\ standard\ values}{Total\ number\ of\ samples} * 100 \quad (2)$$

In case of sample failure, the normalized sum of excursion (NSE) provides the summation of variations in test results from standard values. The excursion offers the deviation of each sample from the standard value, recorded as shown in Equation 4 (CCME, 2001):

$$NSE = \frac{\sum_{i=1}^{n} excursion_i}{Total\ number\ of\ samples} \quad (3)$$

$$Excursion = \frac{Value\ of\ exceeded\ sample}{Standard\ value} - 1 \quad (4)$$

F3 converts the NSE on a scale of 0 to 100 using Equation 5 (CCME, 2001):

$$F_3 = \frac{NSE}{0.01\,NSE + 0.01} \quad (5)$$

The GWQI is evaluated based on the results of F1, F2 and F3, using Equation 6 (CCME, 2001):

$$GWQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}. \quad (6)$$

The denominator in Equation 6 is used to normalize the results from 0 to 100, where 0 suggests the poorest quality of water, while 100 indicates the purest form of water quality. The classification of the score of GWQI is performed in 5 classes, as shown in Table 1, as developed by the Council of Environment Ministers of Canada (CCME, 2001).

Table 1. Grading of GWQI scores

GWQI Score	Rank
95-100	Excellent
80-94	Very Good
65-79	Good
45-64	Marginal
0 - 44	Poor

RESULTS & DISCUSSION

Statistical Distribution of Groundwater Quality

The box-whisker plot provides information about the maximum, minimum, median, upper and lower whiskers and the upper (75th percentile) and lower (25th percentile) quartiles of different parameters. The groundwater parameters were analyzed using statistical methods; i.e., box-whisker plot, as shown in Figure 4, to determine the variations in events over different seasons. Most of the chemical parameters in the study area showed more considerable fluctuations in concentrations with smaller-quartile plots towards the lower quartile. The points above the upper whisker in Figure 4 represent not-so-significant parameter concentration fluctuations, as they are outside the box plots.

All parameters previously defined were evaluated and box-whisker plots were designed. The electrical conductivity (EC) showed significant fluctuations throughout the study period. The maximum value observed is 5166 µS/cm; however, the median remains low, near about 1000 µS/cm, forming a compact box plot where the median is close to the lower quartile. The upper whisker was also found near 2300 µS/cm. The distribution suggests that EC remains low for most of the period and only specific locations are causing the higher value of EC. The maximum value of total hardness (TH) was documented as high as 1670 mg/L compared to the 600 mg/L BIS standard. However, the median was found within the acceptable range and a highly compact box plot was formed within the standard limits, where only a few instances were recorded with a high concentration of TH.

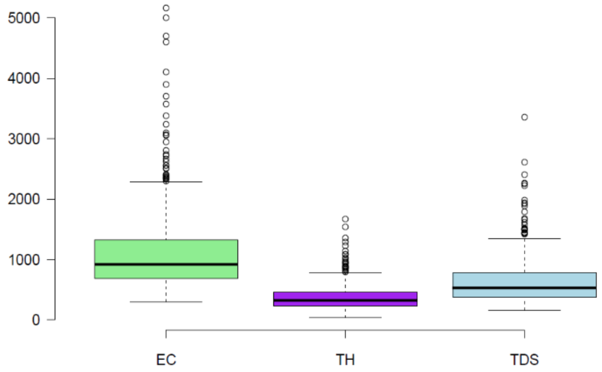

Figure (4): Box-whisker plot of groundwater-quality parameters (EC (µS/cm), TH (mg/L), TDS (mg/L))

The median value of TDS was found below the acceptable range against the standard range of 500-2000 mg/L as per BIS; however, the maximum value was found as 3358 mg/L. The box plot with the lower quartile inclined towards the lower whisker suggests a low concentration of TDS in groundwater samples for most of the period, excluding few samples having a high concentration observed during the monsoon period. The boxplot of EC, TDS and TH is shown in Figure 4.

The average value of other physio-chemical parameters was also found well within the acceptable limit; however, the maximum concentration of each parameter exceeds the expected value, as shown in Figure 5. The box plots of all the parameters inclined towards the lower whiskers and the median was found towards the lower quartile. The maximum value of alkalinity was found to be close to the maximum permissible limit, whereas calcium and magnesium observed a maximum value of 1.5 and 3 times the upper limit, respectively. Nitrates were found to be exceptionally high on a few occasions (10-12 times), whereas the average value was within the acceptable limit. Sulphates were also found with a low average value, with the box plot at the more downside following the permissible limit; however, found exceeding on a few occasions. Fluorides remain low throughout the study period and all the values remain within or near the maximum acceptable limits, as shown in Table 2.

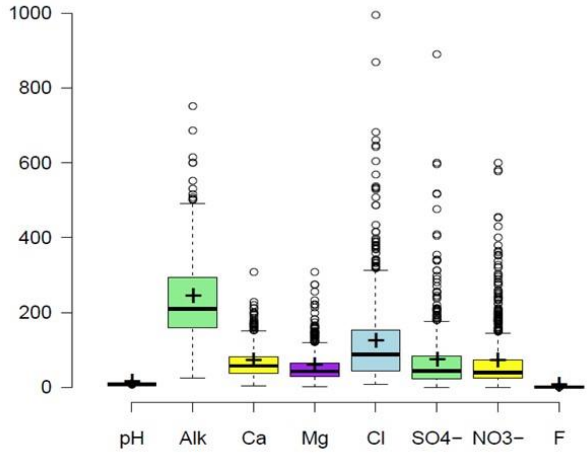

Figure (5): Box-whisker plot of groundwater-quality parameters (pH, Alkalinity (mg/L), Ca (mg/L), Mg (mg/L), Cl (mg/L), SO_4^{2-} (mg/L), NO_3^- (mg/L) and Fluorides (mg/L))

The fluctuation in groundwater quality postulated that destruction in groundwater quality occurs due to the excessive discharge from anthropogenic sources, run-off from agricultural fields and monsoon flow beyond the self-replenishment capacity of groundwater (Barakat et al., 2016; Mukate et al., 2018). The sampling locations that deteriorate groundwater are studied in the next section. The variations in the characteristics of various parameters reflect that agricultural activities are the primary source of ionic variability.

Spatial Distribution of Groundwater Parameters

The groundwater is drenched significantly for meeting the demand for irrigation, followed by industrial and drinking purposes. The BIS 10500:2012 for drinking-water quality is followed to determine the variations in chemical parameters, as the highest-quality water is used for drinking and other domestic activities (BIS, 2012). Several constituents affect the groundwater quality considering the concentrations of several physical, chemical and biological constituents and highly suitable concentrations of all components are required to prepare water for drinking and other purposes. The spatial variability is not restricted to surface watershed boundary, hence the variation in chemical constituents might arise from adjoining areas too.

Table 2. Statistics of average annual data and respective BIS standards

Parameters	Average	Maximum	Minimum	Standard Deviation	BIS Standards
pH	7.90	9.17	6.90	0.31	6.50-8.50
Total Alkalinity (mg/L)	237.28	750.00	25.41	126.62	200.00-600.00
Electrical Conductivity (µS/cm)	930.00	5166.00	300.00	613.42	--
Total Hardness (mg/L)	325.00	1670.00	35.00	193.89	200.00-600.00
Total Dissolved Solids (mg/L)	528.48	3358.00	160.00	372.81	500.00-2000.00
Calcium (mg/L)	57.61	308.00	22.00	38.33	75.00-200.00
Magnesium (mg/L)	42.62	307.60	23.00	38.47	30.00-100.00
Nitrates (mg/L)	40.0	600.16	0.10	78.06	45.00
Sulphates (mg/L)	43.41	890.00	0.10	80.04	200.00-400.00
Fluorides (mg/L)	0.40	1.66	0.01	0.27	1.00-1.50
Chlorides (mg/L)	88.31	994.00	7.00	113.66	250.00-1000.00

The pH distribution was found within the acceptable range throughout the study area. The acceptable pH range is from 6.50 to 8.50 and all the samples were within the defined range. Only a few samples were found near to the upper range in the centre to the east of the Wardha district. The EC measured in µS/cm has an acceptable range based on total dissolved solids' concentration. EC is determined concerning TDS as TDS = k_e * EC, where k_e is the conversions factor and the most common value of k_e is 0.69.

In contrast, the World Health Organization (WHO) allows 1000.0 µS/cm of EC as the maximum permissible concentration. The concentration of EC, found high throughout the Wardha district, suggests high concentrations of dissolved salts in the groundwater. The maximum concentration of EC reached up to 5166.0 µS/cm in a similar area of high pH near the southeast boundary of the district, as shown in Table 2.

The mean concentration of all parameters was found within the permissible limit or below the rejection limit, as per BIS 10500:2012 for drinking water, except for nitrates, which were found on the higher side. The acceptable nitrate limit is 45.00 mg/L without any relaxation on the upper limit (WHO, 2022); however, the average nitrate concentration was 40.00 mg/L. The average magnesium concentration was 42.62 mg/L, which is above the acceptable limit, but within the permissible limit without an alternative source.

The acceptable range of total hardness (TH) for drinking purposes is from 200.0 to 600.0 mg/L and some areas were found with TH greater than 600.0 mg/L. The high level of TH may cause scaling in the pipelines, excessive soap consumption in domestic and industrial activities and calcification of arteries. The few areas of high TH were found in the district's extreme north, southeast, south and southwest boundaries. However, the maximum concentration is not extraordinarily high and could be treated effectively to bring it to the operating range for drinking purposes.

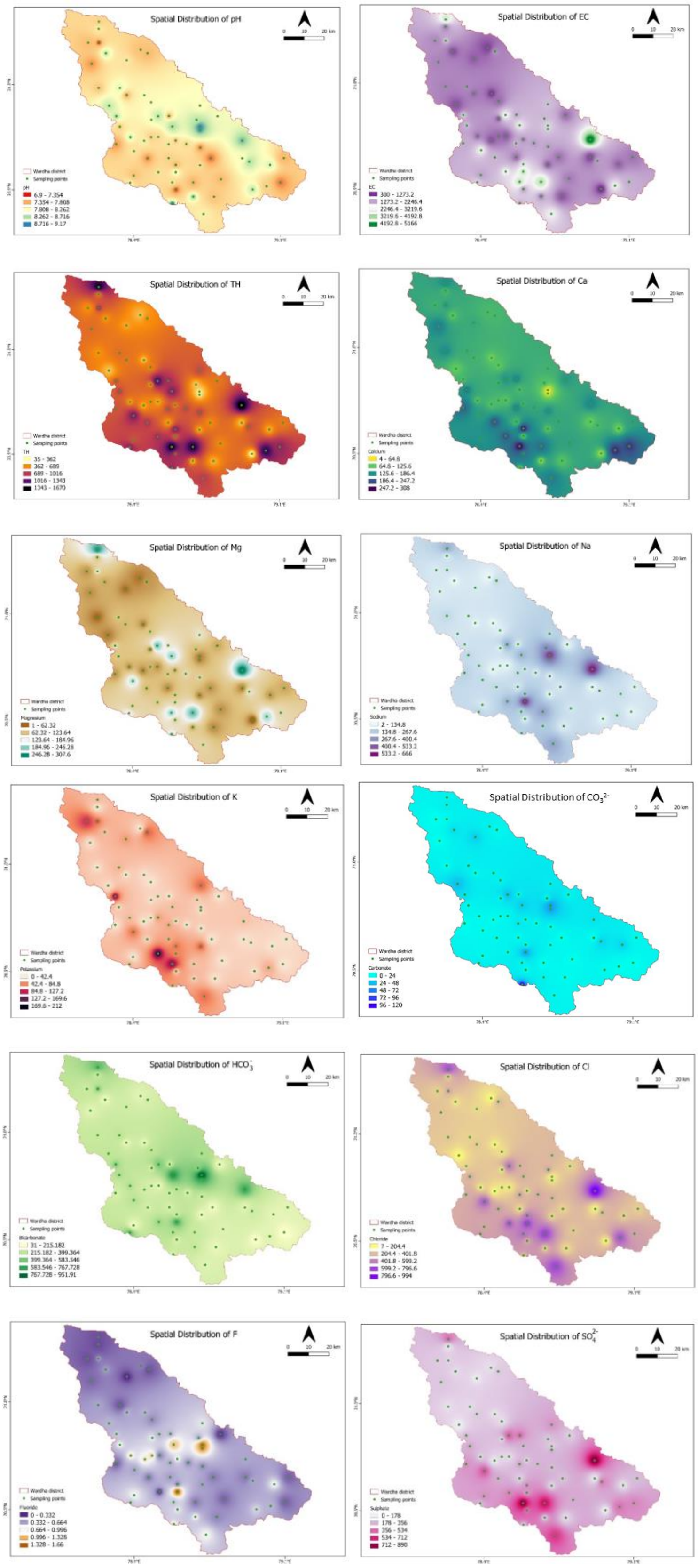

Figure (6): Spatial distribution of different water-quality parameters (F, HCO_3^-, SO_4^{2-}, CO_3^{2-}, Cl, Mg, Na, K, TH, Ca, PH and EC) of Wardha district

The acceptable range of calcium (Ca) for drinking purposes is from 75.0 to 200.0 mg/L. Very few points were found with lower concentrations of Ca. The excessive Ca concentration causes incrustation in pipelines, while a lower concentration of Ca causes rickets. An adequate concentration of Ca is necessary for developing the nervous system, muscles, good cardiac functioning and blood coagulation. High concentrations of Ca in the southeast and southwest parts of the district were found, as shown in Figure 6.

Magnesium (Mg) concentration is important for a healthy life and the human body, as Mg salts are cathartics and diuretics. Cathartics are required for purifying or cleaning bowel movements and diuretics assist in removing excessive salts from the body. However, excessive consumption of Mg is also detrimental, as it causes a laxative effect. The acceptable limit for Mg is 30.0mg/L and could be accepted upto 100.0 mg/L if no other alternatives are available (BIS, 2012). The value of Mg was observed considerably high as 307.6 mg/L in the Wardha district. The high concentration was observed majorly in the extreme north and southeast parts of the district. A smaller area with a high concentration made the water unsuitable for drinking without any specific treatment; however, a large part mainly in the central area of Wardha district indicates that water could be used for drinking or other purposes.

The concentrations of salts, such as Na, K, CO_3^{2-} and HCO_3^-, were also evaluated along with calcium and magnesium concentrations. Na, K, CO_3^{2-} and HCO_3^- concentrations were found within the limits throughout the study area, except for a few regions in the southeast district, as shown in Figure 6. The high value of chlorides (Cl^-) in Wardha groundwater is caused by the excessive run-off from agricultural fields using fertilizers and pesticides or wastewater discharge from septic tanks. The industrial release also raises the Cl concentration (Wagh et al., 2019). The tolerable value of Cl^- is 250.0 mg/L; however, in some areas, Cl^- level rises to 994.0 mg/L, as shown in Figure 6. The extreme north, southeast, southwest and south regions contain high Cl, whereas the rest of the area includes Cl within the acceptable limits. Using water with high Cl mainly harms industries producing food products, beverages, pharmaceuticals and medical items. In similar parts of Wardha district, sulphates were also exceptionally high, with concentrations reaching 890 mg/L. The acceptable value of fluoride (F) in drinking water is 1.0-1.5 mg/L and all samples showed F concentrations in an acceptable range throughout Wardha district. A specific concentration of F is required to prevent mottling of teeth and other bones-related deficiencies, especially in infants. In contrast, excessive consumption of fluoride above 1.5 mg/L for a longer duration may lead to a change in teeth color to yellow and prolonged exposure and consumption cause weakening of bones and dental fluorosis.

The spatial expansion of chemical constituents in groundwater reflects that only a few border areas of the district observe high concentrations, mainly in the extreme north, southeast and southwest regions. However, most of the districts had parameter concentrations within the acceptable limits. The variation in the precipitation rate affects the groundwater recharge and parameter concentrations significantly. The Wardha sub-basin region's rainfall is also known to be affected by El Niño Southern Oscillation (ENSO), which resulted in above-and below-normal rainfall (Rishma and Katpatal, 2019). High concentrations of parameters are majorly caused by the agricultural run-off, followed by seepage from wastewater septic tanks. The seepage of impurities could be removed by applying nano-particles to allow water percolation through the membrane and repel the contaminants, including dissolved salts and heavy metals (Agarwal and Joshi, 2010). The reservoirs in the western part of Nagpur district discharge their run-off in the Wardha district and the topology of the district at the east border attracts water from the Nagpur area. The western boundary of Wardha district is marked along the Wardha river, which is trapped near Kavith village and receives outfall from Bembla dam in Yavatmal district, Maharashtra. The correlation in the concentrations of various parameters also suggests the presence of salts due to the intrusion of urban waste in the groundwater (Peddiwar et al., 2022). The variations in the characteristics of groundwater suggested that the potential sources of pollutants could be either from the study area or from adjoining districts, as the geology of Wardha district allows wastewater discharge from nearby districts.

Groundwater-quality Index

The GWQI was developed using the CCME WQI procedure for drinking purposes based on water-quality standards as per BIS 10500:2012 (BIS, 2012). The results of the developed GWQI are presented in Table 3. The results suggest that groundwater quality of Wardha district witnessed minimal changes throughout the period of the study. The groundwater quality was monitored to be marginal between poor and good from 1990 to 2005 and significantly improved from 2006 to 2010. At the same time, groundwater quality degraded further to marginal from 2011 to 2015 and further enhanced to sound from 2016 to 2019.

The spatial variability of groundwater parameters suggested that the outer boundary of Wardha district near the southeast and southwest borders had parameters with high concentrations and is the primary cause of the overall water-quality deterioration. From 1990 to 2000, 57 samples exceeded standard drinking-water limits; from 2001 to 2005, 39 samples did not meet the shared values and all such samples belonged to similar areas. However, in recent years, the percentage of samples not meeting the standard limits reduced, which was found to improve the water quality, as shown in Table 3. Approximately 50% of samples exceeding the standard limits were of chlorides and sulphates and belonged to similar areas. The high chloride concentration could arise from agricultural run-off, animal waste and feeds. The distribution of water from the Wardha river flows along the border during the high-flow conditions also increases the chloride value in groundwater. In contrast, the consumption of fertilizers during the cropping season and their discharge with agricultural run-off raises the sulphate concentrations in groundwater.

Table 3. Temporal classification of groundwater quality using GWQI

S. No.	Period	No. of Samples	Samples Exceeding Standard Limits	GWQI	Classification
1	1990-2000	249	57	55	Marginal
2	2001-2005	165	39	61	Marginal
3	2006-2010	141	22	68	Good
4	2011-2015	212	40	61	Marginal
5	2016-2019	126	26	68	Good

However, the overall water quality remains good, except for few locations. It could be further improved to very good or to a better class of water quality with the control on the usage of fertilizers and irrigation practices, as well as the generation of minimum run-off from other areas. Applying permeable reactive barriers at the contaminated sites could minimize water-quality degradation (Mathur and Pandey, 2017).

CONCLUSIONS

Groundwater samples were analyzed from 68 dug wells in Wardha district of Maharashtra. The spatial distribution of groundwater physio-chemical constituents was determined to identify the appropriateness of groundwater for different purposes. The spatial expansion clearly describes the variations of various parameters along the study area. The study area's pH, Na, K, CO_3^{2-}, HCO_3^- and fluoride were well within the accepted limits. EC, Ca, Mg, TH, sulphates and chlorides were found marginally above the rejection limits. Most parameters were high in similar locations; i.e., southeast, southwest and extreme north. The maximum concentrations of magnesium, nitrates and sulphates were found as 307.6 mg/L, 600.16 mg/L and 890.0 mg/L, being 3.1 times, 13.3 times and 2.25 times higher than the standard acceptable limits, respectively. The high concentration of salts could be attributed to the agricultural run-off containing fertilizers, industrial discharge through open drains and release from septic tanks. Sulphates and chlorides are the significant parameters with the highest number of samples exceeding the standard limits and the highest chances of disposal from agricultural run-off. The GWQI values suggest that water quality remains within the marginal category for most of the period and has improved to good in recent years.

Further improvement in water quality could be achieved through controlled usage of fertilizers and irrigation water to minimize run-off discharges. The findings could assist decision-makers in categorizing water resources for drinking and agricultural purposes. Tapping individual industrial and domestic wastewater origins to identify the quantum of pollution load could provide an exact contribution of point sources to groundwater contamination compared to agricultural sources.

Limitations of Study

The present study is based on spatial analysis of groundwater samples and the development of the WQI index, whereas the analysis is based on physio-chemical parameters. Including heavy metals in the investigation could provide new information about the study area. Integrating machine-learning techniques may bring new insights and improve the model's accuracy.

REFERENCES

Agarwal, A., and Joshi, H. (2010). “Application of nano-technology in the remediation of contaminated groundwater: A short review”. Recent Research in Science and Technology, 2(6), 51-57.

Akhtar, N., Ishak, M.I.S., Ahmad, M.I., Umar, K., Md Yusuff, M.S., Anees, M.T., Qadir, A., and Ali Almanasir, Y.K. (2021). “Modification of the water-quality index (WQI) process for simple calculation using the multi-criteria decision-making (MCDM) method: A review”. Water, 13 (7), 905.

Alemu, C.M., Aycheh, Y.F., Angualie, G.S., and Ejigu, K.M. (2022). “Modeling on comprehensive evaluation of groundwater-quality status using geographic information system (GIS) and water-quality index (WQI) in case of Bahir Dar city, Amhara, Ethiopia”.

APHA. (2005). “Standard methods for the examination of water and wastewater”. 21st edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC.

Arora, S., and Keshari, A.K. (2021). “Pattern recognition of water-quality variance in Yamuna river (India) using hierarchical agglomerative cluster and principal-component analyses”. Environmental Monitoring and Assessment, 193, 1-18.

Banacos, P.C. (2011). “Box-whisker plots for local climate datasets: Interpretation and creation using Excel 2007/2010”.

Barakat, A., El Baghdadi, M., Rais, J., Aghezzaf, B., and Slassi, M. (2016). “Assessment of spatial and seasonal water-quality variation of Oum Er Rbia river (Morocco) using multi-variate statistical techniques”. International Soil and Water Conservation Research, 4 (4), 284-292.

Bawoke, G.T., and Anteneh, Z.L. (2020). “Spatial assessment and appraisal of groundwater suitability for drinking consumption in Andasa watershed using water-quality index (WQI) and GIS techniques: Blue Nile basin, northwestern Ethiopia”. Cogent Engineering, 7 (1), 1748950.

Canadian Council of Ministers of the Environment. (2001). "Canadian water-quality guidelines for the protection of aquatic life: CCME water-quality index 1.0, user's manual". In: Canadian Environmental Quality Guidelines, 1999, Winnipeg.

CGWB. (2021). “Aquifer map and groundwater management plan, Wardha district, Maharashtra, 2019-2020”.

Dandge, K.P., and Patil, S.S. (2022). “Spatial distribution of groundwater-quality index using remote-sensing and GIS techniques”. Applied Water Science, 12 (1), 1-18.

Duraisamy, S., Govindhaswamy, V., Duraisamy, K., Krishinaraj, S., Balasubramanian, A., and Thirumalaisamy, S. (2019). “Hydrogeochemical characterization and evaluation of groundwater quality in Kangayam taluk, Tirupur district, Tamil Nadu, India, using GIS techniques”. Environmental Geochemistry and Health, 41 (2), 851-873.

Fang, Y., Zheng, T., Zheng, X., Peng, H., Wang, H., Xin, J., and Zhang, B. (2020). "Assessment of the hydrodynamics role for groundwater quality using an integration of GIS, water-quality index and multi-variate statistical techniques". Journal of Environmental Management, 273, 111185.

Goitsemang, T., Das, D.M., Raul, S.K., Subudhi, C.R., and Panigrahi, B. (2020). "Assessment of groundwater potential in the Kalahandi district of Odisha (India) using remote sensing, geographic information system and analytical hierarchy process". Journal of the Indian Society of Remote Sensing, 48 (12), 1739-1753.

Hosseininia, M., and Hassanzadeh, R. (2023). "Groundwater-quality assessment for domestic and agricultural purposes using GIS, hydrochemical facies and water-quality indices: Case study of Rafsanjan plain, Kerman province, Iran". Applied Water Science, 13 (3), 84.

Hurley, T., Sadiq, R., and Mazumder, A. (2012). "Adaptation and evaluation of the Canadian council of ministers of the environment water-quality index (CCME WQI) for use as an effective tool to characterize drinking-water quality". Water Research, 46 (11), 3544-3552.

Kalhor, K., Ghasemizadeh, R., Rajic, L., and Alshawabkeh, A. (2019). "Assessment of groundwater quality and remediation in karst aquifers: A review". Groundwater for Sustainable Development, 8, 104-121.

Kawo, N.S., and Karuppannan, S. (2018). "Groundwater-quality assessment using water-quality index and GIS technique in Modjo river basin, central Ethiopia". Journal of African Earth Sciences, 147, 300-311.

Khafaji, M.S.A., Alwan, I.A., Khalaf, A.G., Bhat, S.A., and Kuriqi, A. (2022). "Potential use of groundwater for irrigation purposes in the middle Euphrates region, Iraq". Sustainable Water Resources Management, 8 (5), 1-14.

Khatri, N., and Tyagi, S. (2015). "Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas". Frontiers in Life Science, 8 (1), 23-39.

Knüppe, K. (2011). "The challenges facing sustainable and adaptive groundwater management in South Africa". Water Sa, 37 (1), 67-80.

Kumar, S., Dhyani, B.L., and Singh, R.J. (2013). "Depleting groundwater resources of Rajasthan state and its implications". Popular Kheti, 1 (3), 64-68.

Lumb, A., Sharma, T.C., and Bibeault, J.F. (2011). "A review of genesis and evolution of water-quality index (WQI) and some future directions". Water Quality, Exposure and Health, 3 (1), 11-24.

Machiwal, D., Cloutier, V., Güler, C., and Kazakis, N. (2018). "A review of GIS-integrated statistical techniques for groundwater-quality evaluation and protection". Environmental Earth Sciences, 77 (19), 1-30.

Mathur, S., and Pandey, P. (2017). "Optimal design of in-*situ* permeable reactive barrier". WIT Transactions on Ecology and the Environment, 216, 251-259.

Mithani, I., Dahegaonkar, N.R., Shinde, J.S., and Tummawar, S.D. (2012). "Preliminary studies on physico-chemical parameters of Wardha river, Chandrapur district, Maharashtra". Journal of Research in Ecology, 1, 14-18.

Mukate, S., Panaskar, D., Wagh, V., Muley, A., Jangam, C., and Pawar, R. (2018). "Impact of anthropogenic inputs on water quality in Chincholi industrial area of Solapur, Maharashtra, India". Groundwater for Sustainable Development, 7, 359-371.

Omar, P.J., Dwivedi, S.B., and Dikshit, P.K.S. (2020). "Sustainable development and management of groundwater in Varanasi, India". In: Advances in Water Resources Engineering and Management: Select Proceedings of TRACE 2018 (201-209). Springer Singapore.

Pande, C.B., Moharir, K.N., Singh, S.K., and Dzwairo, B. (2020). "Groundwater evaluation for drinking purposes using statistical index: Study of Akola and Buldhana districts of Maharashtra, India". Environment, Development and Sustainability, 22 (8), 7453-7471.

Peddiwar, S.T., Ingole, D.K., and Nimbarte, G.R. (2022). "Groundwater-quality assessment and its insinuations in some parts of Aheri taluka dist.-Gadchiroli, Maharashtra". In: IOP Conference Series: Earth and Environmental Sciences 1032 (1), 012021. IOP Publishing.

Poonam, T., Tanushree, B., and Sukalyan, C. (2013). "Water-quality indices: Important tools for water-quality assessment: A review". International Journal of Advances in Chemistry, 1 (1), 15-28.

Ram, A., Tiwari, S.K., Pandey, H.K., Chaurasia, A.K., Singh, S., and Singh, Y.V. (2021). "Groundwater-quality assessment using water-quality index (WQI) under GIS framework". Applied Water Science, 11, 1-20.

Ravi, R., Aravindan, S., Shankar, K., and Balamurugan, P. (2020). "Suitability of groundwater quality for irrigation in and around the main Gadilam river basin on the east coast of southern India". Archives of Agriculture and Environmental Science, 5 (4), 554-562.

Ravichandran, R., Ayyavoo, R., Rajangam, L., Madasamy, N., Murugaiyan, B., and Shanmugam, S. (2023). "Comparative analysis of groundwater-quality index for bhavani river basin using remote sensing and statistical analysis". Jordan Journal of Civil Engineering, 17 (1), 58-68.

Ravindra, K., Thind, P.S., Mor, S., Singh, T., and Mor, S. (2019). "Evaluation of groundwater contamination in Chandigarh: Source identification and health-risk assessment". Environmental Pollution, 255, 113062.

Rawat, K.S., and Singh, S.K. (2018). "Water-quality indices and GIS-based evaluation of a decadal groundwater quality". Geology, Ecology and Landscapes, 2 (4), 240-255.

Ray, S., and Ray, I.A. (2011). "Impact of population growth on environmental degradation: Case of India". Journal of Economics and Sustainable Development, 2 (8), 72-77.

Rishma, C., and Katpatal, Y.B. (2019). "ENSO modulated groundwater variations in a river basin of central India". Hydrology Research, 50 (2), 793-806.

Sadat-Noori, S.M., Ebrahimi, K., and Liaghat, A.M. (2014). "Groundwater-quality assessment using the water-quality index and GIS in Saveh-Nobaran aquifer, Iran". Environmental Earth Sciences, 71 (9), 3827-3843.

Şener, Ş., Şener, E., and Davraz, A. (2017). "Evaluation of water quality using water-quality index (WQI) method and GIS in Aksu river (SW Turkey). "Science of the Total Environment, 584, 131-144.

Singh, S.K., and Noori, A.R. (2022). "Groundwater-quality assessment and modeling utilizing water-quality index and GIS in Kabul basin, Afghanistan". Environmental Monitoring and Assessment, 194 (10), 673.

Subba Rao, N., Sunitha, B., Adimalla, N., and Chaudhary, M. (2020). "Quality criteria for groundwater use from a rural part of Wanaparthy district, Telangana state, India, through ionic spatial distribution (ISD), entropy water-quality index (EWQI) and principal-component analysis (PCA)". Environmental Geochemistry and Health, 42 (2), 579-599.

Sunitha, V., and Reddy, B.M. (2022). "Geochemical characterization, deciphering groundwater quality using pollution index of groundwater (PIG), water-quality index (WQI) and geographical information system (GIS) in hard-rock aquifer, South India". Applied Water Science, 12 (3), 1-20.

Vaiphei, S.P., Kurakalva, R.M., and Sahadevan, D.K. (2020). "Water-quality index and GIS-based technique for assessment of groundwater quality in Wanaparthy watershed, Telangana, India". Environmental Science and Pollution Research, 27 (36), 45041-45062.

Wagh, V.M., Panaskar, D.B., Jacobs, J.A., Mukate, S.V., Muley, A.A., and Kadam, A.K. (2019). "Influence of hydro-geochemical processes on groundwater quality through geostatistical techniques in Kadava river basin, western India". Arabian Journal of Geosciences, 12 (1), 1-25.

WHO. (2022). "Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda". Geneva: World Health Organization.