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Application of the Weighted Arithmetic Water Quality Index in Assessing Groundwater Quality: A Case Study of the South Gujarat Region

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Abstract: Groundwater is a natural resource used for drinking, agriculture, and industry, apart from surface water. Its quality should be assessed regularly, and the condition of water resources should be maintained accordingly. The most common analytical method for describing and assessing the general water quality is the Water Quality Index (WQI). This study aims to assess the South Gujarat Region's groundwater quality using the WQI. Various physicochemical parameters like pH, turbidity, total dissolved solids, total hardness, calcium, magnesium, chloride, sulphate, nitrate, fluorides, and total alkalinity are considered for the present study. The data period from 2018 to 2022 is considered for the same. The Weighted Arithmetic Water Quality Index Technique is used to evaluate these data. For checking the potability of the parameters within the acceptable limit, the Indian Standard Drinking Water Specification code (IS: 10050-2012) is adopted. According to the study mentioned above, a few wells' groundwater quality has been found to be higher than the WQI value. It is also observed that four wells were found unsuitable for drinking purposes in 2018. It is noted that if the WQI value of groundwater is above 51, it is considered harmful to human health; therefore, it requires some kind of processing before use. This study will be beneficial to the policymakers for identifying and providing details about groundwater quality in the form of a specific value, i.e., WQI.

Keywords: groundwater quality; physicochemical parameters; standard values; water quality index

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Citation: Patel, D.D.; Mehta, D.J.; Azamathulla, H.M.; Shaikh, M.M.; Jha, S.; Rathnayake, U. Application of the Weighted Arithmetic Water Quality Index in Assessing Groundwater Quality: A Case Study of the South Gujarat Region. *Water* **2023**, *15*, 3512. https://doi.org/10.3390/w15193512

Academic Editors: Guilin Han, Daniela Mesquita and Cristina Quintelas

Received: 25 August 2023
Revised: 15 September 2023
Accepted: 26 September 2023
Published: 8 October 2023

1. Introduction

The term "groundwater" refers to water that is present underground in saturated areas below the surface. India's massive rural and urban populations, the ecosystem, and agriculture are all significantly impacted by the country's water crisis [1]. India has nearly 1.39 billion people, yet just 4% of the world's freshwater resources. Groundwater makes up around 30% of the world's readily accessible fresh water. Surface water and groundwater are the only two main sources of drinking water [2]. Groundwater resources are employed for many various purposes: drinking; irrigation; and industrial uses. Groundwater is typically used by farmers to irrigate their crops more frequently than other sources, such as surface water [3]. Groundwater quality and quantity are significantly impacted by both natural and man-made activities [4,5].

Almost 80% of human illnesses, according to the report of the World Health Organisation (WHO), are brought on by contaminated water [6]. Seasonal variations, depth, the subsurface environment, and leached dissolved salts all affect groundwater quality differently [7]. As a result, monitoring and management of groundwater and surface water are now essential processes for sustainable development to establish the availability of freshwater [8,9]. Although some groundwater is a renewable resource that may be recharged by rains and snowmelt, it can be depleted if used more quickly than it can be restored [10]. Physical, chemical, and biological properties are three different categories of water quality. These parameters are dangerous if their values are outside the ranges specified [11]. Sodium, calcium, magnesium, potassium, chloride, bicarbonate, sulphate, and other dissolved minerals are the most common [12].

The majority of South Gujarat is classified as having a coastal ecosystem and a subtropical climate, with considerable variability in climatic parameters is seen at the taluka level. The entire eastern strip is classed as subhumid (moist/dry), but the southeast region, which includes Gandevi taluka of Navsari district, is humid [13]. The most significant issues in the command region of South Gujarat include secondary salinisation and waterlogging brought on by heavy textured soils, high rainfall, deviations from recommended crop patterns, improper irrigation practices, etc. [14]. The district and source-specific irrigated and daily consumption area indicate that ground and surface water resources in South Gujarat contribute nearly equally, at 46% and 54%, respectively, According to research on water management in South Gujarat [15]. According to a district report survey conducted in 2022 from February to March, 82% of villages reported having improved dug and bore wells, and 9% had recharging structures.

However, assessing water quality poses several difficulties, including the need for extensive sample collection, lab testing, and data processing. It is difficult for the local public to know and describe the quality of water, and for certain uses, they are unable to describe the impact of a single parameter. There are numerous techniques, such as analytical, modelling, remote sensing, and sampling and analysis of the water quality [16]. The Water Quality Index is one of the methods used for measuring the quality of water. WQI can reduce a large volume of data into a specific term and present the facts in a clear, logical manner [17,18]. The WQI concept was first introduced by Horton in 1965, and later, various studies have been carried out by different researchers to understand the ground water quality [19]. The weighted arithmetic water quality index method is a modified form of Horton's formula, created by Brown et al. (1970). WQI, a way of assessing or classifying the quality of water type, is effective for determining the regional and physical variance in groundwater conditions and providing knowledge on water quality to concerned locals and policymakers [20,21].

Artificial intelligence (AI) and its potential uses for managing and monitoring water quality are currently gaining more interest [22]. For processing, evaluating, and identifying the quality of a water resource, groundwater quality data are essential. Based on WQIs, classifying groundwater becomes much more practical. Water quality indices (WQIs) are mathematical tools employed to classify water quality [23,24]. By combining different datasets to generate a single number that represents the quality of the water, problems with water quality can be more easily understood. It offers data on groundwater quality and serves as a reliable, consistent unit of measurement. The WQI cannot be accurately represented by a numerical value that precisely captures the physicochemical and biological properties of water. WQI is typically calculated using measurements of T°C, electrical conductivity (EC), organic matter, metals, and all other parameters [25]. Due to its ability to determine the final state of the water quality without interpreting each variable, it has an advantage over other evaluation techniques [26,27].

Different calculation techniques have been introduced or used in the field of hydrology for prediction, analysis, equation formation, etc. [28]. The water quality simulation method has a few benefits, including low or no simulation cost, quick simulation time, reduced need for measurement or laboratory equipment and staff, ability to generate significant amounts of synthetic data for analysis, regeneration of data gaps, measurement, and control calibration equipment, and ability to generate large amounts of data quickly [29]. To save time and effort, an artificial neural network (ANN) method has recently been used to estimate groundwater quality [30]. In the area of water quality modelling, ANNs have found a variety of uses [31]

It gives data on groundwater quality and works as a consistent, precise unit of measurement [32]. Although WQI cannot be accurately expressed, as mentioned above, WQI can determine the water quality's final state without conducting an interpretation of each variable, which gives it an edge over other evaluation methods [33].

To know the water quality of the district and to demonstrate the capacity and use of the Weighted Arithmetic Water Quality Index method for the groundwater quality has been carried out. According to the survey, the water quality of the wells is good quality rather than excellent water quality type, but sometimes they need treatment before consumption [34]. The review obtained regarding the tap water system by the government body has not yet covered the whole district area. Moreover, in some of the villages, there is no proper drainage alignment; therefore, sometimes, there is a chance of dirty water infiltrating into the ground. This present work's main objective is to employ WQI to find out if the state of groundwater in the South Gujarat Region is acceptable for drinking purposes. The study area is located between 20.07 to 21.00 North Latitude and 72.43 to 73.00 East Longitude. Also, the impact of each parameter, as well as the attentiveness of the physicochemical parameters is assessed for the research areas and status of groundwater quality.

2. Materials and Methods

2.1. Study Area and Data Collection

The Navsari district is located on the Arabian Sea coast on the southern edge of the Gujarat state. It is situated between latitudes 20.07 and 21.00 in the north and 72.43 and 73.00 in the east. The district has an area of 2196 km^2 and a population of 1,329,672 per the 2011 Census. The district has a total area of 2246 km^2, of which 73 km^2 is urban and 2173 km^2 is rural. Due to its location in the southern part of the state, four physiographic units have been formed there: (1) Top Relief Zone; (2) Zone in the Piedmont; (3) Alluvial Plain; and (4) The Coastal Plain. The terrain and lineaments of the district regulate the drainage. The main and secondary porosity of the interrelated geological units that make up the aquifers, as well as the distribution of rainfall and falls, all play a significant role in the hydrogeological framework of the region. Because of the rapid expansion of industrialisation in the western portion of Navsari in recent years, groundwater pollution has increased. Due to groundwater depletion, rivers and ponds drying up, and other factors, there is a severe water shortage in some regions of the Vansda and Chikhali taluka, as per the news in 2019. According to an article in 2022, locals were reluctant to walk 2–3 km for drinking water since it would be contaminated in the steep sections or the interior villages of the district despite the district receiving the most rainfall.

Rural areas where groundwater is used for drinking and other reasons are the subject area for this study. The analysis is carried out to obtain the quality and water type of groundwater sources (wells) and variations in the WQI values for consecutive years, for the study data for the sites (wells) are gathered from the government body-GWSSB Laboratory, Navsari. The data period is from 2018 to 2022. Microsoft Office Excel 2021 was used to do statistical analyses on the data that had been collected. The sites where the wells are located are represented as N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13, N14, N15, N16, N17, N18, N19, N20, N21, N22, N23, N24, N25 for Kalvach, Endhal, Masa Gamtal, Dhikri, Harijansvas, Tavdi, Chokhad, Parsoli, Kachhol, Khadsupa, Parthan, Mahudi, Maliadhara, Hond, Gholar, Pipalgabhan, Donja, Achhavani, Jamanpada, Toranvera, Debarpada, Kandha Bari, Khadkbari, Rawaniya, Vaghabari, respectively. Figure 1 shows the study area map of the South Gujarat Region.

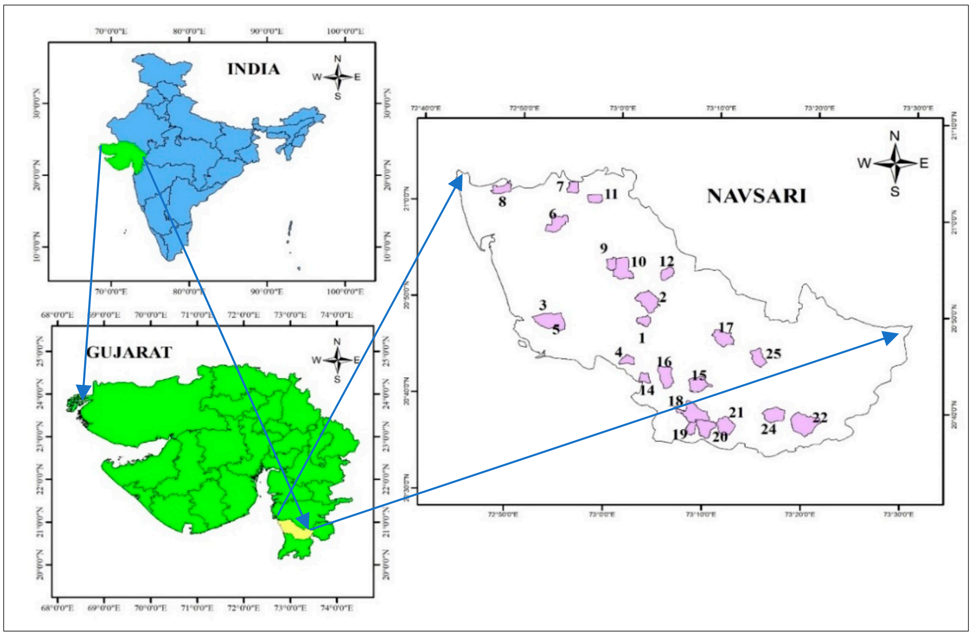

Figure 1. Study area map.

2.2. Methods

The laboratory used the 23rd APHA method for the collection and testing of water quality parameters for the assessment of groundwater quality. Following the recommendations made by the Indian Standard Drinking Water Specification Code, the values of the specified physical and chemical parameters were evaluated [35]. Several other water quality factors were measured by an analytical technique called the WQI, which determines how they affect the water's overall quality.

Water Quality Index studies (Horton 1965; Landwehr and Deininger 1976; Brown 1972; Steinhart 1982; Canadian Council of Ministers of the Environment (CCME), 2005; Bhargava, 1983, and many others) have reported on the various techniques used for calculating WQI and for comparing physicochemical parameters with the recommendations in the literature. Horton introduced the WQI in 1965, and other various approaches for its calculation have subsequently been introduced or modified in the literature [20]. The WQIs can be considered as simplified representations of a complicated reality or models for water quality, where variables are chosen, and weighting and aggregation methods are defined [1]. Using the most frequently measured water quality parameters, the weighted arithmetic water quality index technique assessed the water quality according to the degree of purity [30]. It has been applied repeatedly. Although this method was employed in surface water research, the majority of investigations on the various conditions found that it succeeded when applied to groundwater studies. An assessment of the WQI was carried out using the WAWQI method in the following studies [21,22]. Analysis of eleven parameters of water quality was carried out (pH, turbidity, total dissolved solids, total hardness, calcium, magnesium, chloride, sulphate, nitrate, fluorides, and total alkalinity). The potability of the variables was considered using the Bureau of Indian Standards (BIS) [35]. The WQI values for the research area were determined independently for the considered years.

The WAWQI method was used in this study, consisting of 4 steps, which are as follows [23,24]:

1. Select parameters to measure the quality of the groundwater;
2. Quality ratings are scaled for each parameter;
3. The unit weight (W_i) is calculated, and W_i is inversely dependent upon the standard value (S_i) of the parameters recommended;
4. Calculating the overall WQI by summing the subindex value.

The following equations were used to calculate the WQI. Each water quality parameter's unit weight (W_i) was computed using Equation (1) as follows [25,26]:

$$W_i = \frac{K}{S_i} \tag{1}$$

where W_i stands for the unit weight of ith parameters. K is a proportionality constant. S_i is the standard value of each parameter [35].

$$K = \frac{1}{\Sigma \frac{1}{S_i}} \tag{2}$$

Each parameter's quality rating scale (Q_i) was calculated using Equation (3):

$$Q_i = \left(\frac{V_i - V_0}{S_i - V_0} \right) \tag{3}$$

For the pH, the quality rating scale was determined by Equation (4),

$$Q_i = \left(\frac{V_i - 7}{S_i - 7} \right) \tag{4}$$

where V_i is the concentration value for the ith analysed parameter and V_0 is the ideal value of the parameter. Whereas, except for pH (ideal value 7, all other parameter's ideal value is zero. The final equation can be presented in Equation (5).

$$\begin{gathered} SI_i = \frac{\Sigma W_i Q_i}{\Sigma W_i} \\ WQI = \sum SI_i \end{gathered} \tag{5}$$

SI_i is the subindex of the ith parameter and i represents the number of parameters taken into consideration [5,27]. In Table 1, the ideal values and unit weights for the water quality variables and their standard values are shown [10,30].

Table 1. Standard limits for parameters (BIS IS–10500:2012).

Sr. No.	Parameters	Acceptable Limit	Ideal Values (V_0)	K	Wi
1	pH	6.5–8.5	7	0.710461	0.083584
2	Turbidity	1	0	0.710461	0.083584
3	TDS	500	0	0.710461	0.001421
4	Total Hardness	200	0	0.710461	0.003552
5	Calcium	75	0	0.710461	0.009473
6	Magnesium	30	0	0.710461	0.023682
7	Chloride	250	0	0.710461	0.002842
8	Sulfate	200	0	0.710461	0.003552
9	Nitrate	45	0	0.710461	0.015788
10	Fluoride	1	0	0.710461	0.710461
11	Total Alkalinity	200	0	0.710461	0.003552

3. Results and Discussion

The physicochemical parameters of groundwater assessed for the open wells were compared and evaluated against the BIS (10500: 2012) drinking water quality standards. Table 2 shows the range of water quality according to the Weight Arithmetic Water Quality Index method [26,27]. It was noted that the concentration of various parameters in Table 3 was high and had surpassed the acceptable limit for the area (number of wells) under consideration. In the majority of the cases, the TDS, TH, Ca, Mg, Cl, and total alkalinity concentrations were higher than the allowable limit for the specific year and well number. It has been noted that the TH, TDS, Mg, and total alkalinity influence the water quality and contribute to the WQI with other parameters. Total hardness and TDS, on the other hand, were much higher than the values for TH and TDS given in the BIS guidelines. None of the wells had pH, nitrate, or turbidity contents above the allowable limits. Whilst calcium and chloride hardly changed in wells over the different periods. Fluoride levels in the water were raised in wells 3 and 18. With rising values for these parameters, the WQI score increases. WQI, which is often used for the recognition and analysis of groundwater quality and state of pollution, can be considered as the representation of the combined impact of various water quality variables on the overall water quality [28]. The ecological status of water may be assessed using the WQI value produced using the WAWQI method procedure. The WQI value rises with increasing values of these parameters.

Table 2. Water quality range as per WAWQI.

WQI	Water Types (Class)
0–25	Excellent Water
26–50	Good Water
51–75	Poor Water
76–100	Very Poor Water
Above 100	Water Unsuitable for Drinking Purposes

Table 3. Physicochemical parameters analysed and comparison with BIS-IS: 10050-2012.

Site	Year	TDS	TH	Mg	F	Cl	Alkalinity	Ca
N1	2018	765	235	35			452	
N2	2018	910	493	60			412	99
N3	2018	602	289	31	1.4		291	
N4	2018	950	323	39		523	404	
N5	2018	3164	1471	178		1034	291	295
N6	2018	674	356	43			226	
N8	2018	770	323	39			331	
N7	2018	846	461	53			315	92
N9	2018	652					259	
N10	2018	820	541	66		404	108	
	2019	570	218			424		
	2020	3896	1519	184		4122	549	304
	2021	887	553	68				110
	2022	901	398	60			558	99
N11	2018	598	396	48			275	79
	2019	660	242				218	
	2020	984	404	49			582	89
	2021	965	400	45		258	497	83
	2022	897	391	39			572	77
N12	2018	384	250				250	
	2019	320	275	33			356	
	2020	556	331	40			339	
	2021	680	337	41			456	
	2022	620	325	39			383	
N13	2018	840	242				525	
N14	2018	1020	444	54		323	428	89
	2019	642	634	44			226	
	2020	765	397	63			369	79
N15	2018	598	396	48			275	79
	2020		250					
N16	2018	628	420	51			356	84
N17	2018	560	267	32			210	
N18	2018	624	384	56	1.26		232	
	2019		246				300	
	2022	524	240					
N19	2018	398	234					

Table 3. *Cont.*

Site	Year	TDS	TH	Mg	F	Cl	Alkalinity	Ca
N20	2018		222					
	2019		265	33				
	2020		232					
	2021		224					
N21	2018		284				236	
	2019		320	39				
	2020	559	338	40			265	
	2021		232					
	2022	628	360	44			244	
N22	2018		216					
	2019		232					
	2020	614	232				344	
	2022		239					
N23	2018		208	31			204	
	2019		216					
	2020		232					
	2022		242					

A low range in the WQI indicates the best water quality, whilst a higher number indicates poor quality, according to the range. Estimated WQI values for the locations ranged from 18.29 to 94.76, which corresponds to good to extremely poor water quality, and between 100 and 137, which corresponds to water that is unfit for drinking. Three samples from the research area had very poor water quality, and six samples had poor water. In the study area, 14 samples resulted in excellent water, and 25 samples had good water quality during the years of analysis. Four samples were not fit to be consumed as drinking water, and the groundwater from such places needs to undergo thorough water treatment before use. The categorisation of the obtained results according to the WQI classification is presented in Table 4.

According to the range of the WQI, a low number denotes the best water quality, whilst a higher number denotes the worst quality. Table 4 shows the calculated WQI values for the study area. The WQI for wells N1, N2, N5, N6, N7, N8, N10, N11, N15, N16, N17, N22, N23, and N24 was between 0 and 25, which indicates excellent quality of water. The remaining wells had WQI values that ranged from 26.8938 to 50.4052, which indicates good water quality, whereas a value between 100 and 137 corresponds to water that is unfit for drinking. Three samples from the study area had extremely poor water quality, and six samples had poor water quality.

Table 4. Categorisation of obtained results according to the WQI classification.

Sr. No.	WQI	Status	Site	Year
1	0–25	Excellent water	N1	2018
			N2	2019
			N5	2019
			N6	2018, 2021, 2022
			N7	2019
			N8	2021
			N10	2019
			N11	2018
			N15	2018
			N16	2019, 2021, 2022
			N17	2018
			N22	2018
			N23	2018, 2020
			N24	2021

Table 4. *Cont.*

Sr. No.	WQI	Status	Site	Year
2	25–50	Good Water	N1	2019, 2020, 2021, 2022
			N2	2020, 2021
			N3	2019, 2020, 2021, 2022
			N4	2019, 2020, 2021, 2022
			N5	2020, 2021, 2022
			N6	2019, 2020
			N7	2020, 2021, 2022
			N8	2018, 2019, 2020, 2021, 2022
			N9	2018, 2019, 2020, 2021, 2022
			N10	2018, 2020, 2021, 2022
			N11	2019, 2020, 2021, 2022
			N12	2018, 2019, 2020, 2021, 2022
			N13	2018, 2019, 2020, 2021, 2022
			N14	2018, 2019, 2020, 2021, 2022
			N15	2019, 2022
			N16	2020
			N17	2019, 2020, 2021, 2022
			N18	2019
			N19	2019, 2020, 2021, 2022
			N20	2021, 2022
			N21	2018, 2019, 2020, 2021, 2022
			N22	2019, 2020, 2021, 2022
			N23	2019, 2021, 2022
			N24	2018, 2019, 2020, 2022
			N25	2018, 2019, 2020, 2021, 2022
3	51–75	Poor Water	N2	2022
			N8	2018
			N15	2020, 2021
			N16	2018
			N18	2020, 2021, 2022
			N20	2018
4	76–100	Very poor water	N2	2018
			N7	2018
			N20	2019
5	Above 100	Water Unsuitable for Drinking Purposes	N3	2018
			N4	2018
			N5	2018
			N18	2018
			N20	2020

4. Conclusions

The WQI approach used in the current study to analyse sites' groundwater quality was helpful. According to the WQI value, the majority of the sites had high water quality, which was followed in descending order by excellent water, poor water, unfit for drinking water, and extremely poor water quality. These data were also used to monitor annual fluctuations in the concentration values of nutrients in groundwater. The results found the total hardness and TDS levels were observed to be at or above the permitted limit for the period taken into consideration and for all sites. This indicates one reason for the WQI value to be impacted in the groundwater. The advantage of the WAWQI approach is that it combines data from numerous groundwater quality parameters into a mathematical equation that depicts the water's ecological state. Additionally, it shows the significance that each parameter has in the evaluation and control of the quality of water and can be used to define whether a source of groundwater is fit for human use.

Author Contributions: Conceptualisation, D.J.M.; methodology, D.D.P.; software, D.D.P.; validation, H.M.A. and M.M.S.; formal analysis, D.D.P.; investigation, D.D.P.; resources, D.J.M. and S.J.; data curation, D.J.M.; writing—original draft preparation, D.D.P.; writing—review and editing, D.J.M. and U.R.; visualisation, D.D.P.; supervision, D.J.M.; project administration, U.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data are only available for research purposes from the corresponding author.

Acknowledgments: The precipitation data used in this study were provided by the Water Resource Department, Raipur Chhattisgarh (CGWRD), and reservoir release corresponding to demand were made available from the Water Resource Department (Mahanadi reservoir project complex), Rudri division, Chhattisgarh, and are highly appreciated. Suggestions and comments from reviewers are greatly acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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