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Review on Assessment of the Groundwater Quality Using the Groundwater Quality Index & Field Investigation Using Geo-Informatics Approach

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ABSTRACT

Groundwater is a vital resource for human consumption and agriculture. However, its quality can be impacted by various factors, including natural processes by the different geogenic factors and anthropogenic factors. This study aims to conduct a comparative analysis of groundwater quality in the study area to assess its suitability for different uses. The analysis will involve collecting groundwater samples from various locations and analyzing them for key chemical parameters like pH, electrical conductivity, total dissolved solids, major ions, and trace elements. The results will be compared with relevant standards to determine the suitability of the groundwater for drinking, irrigation, and other purposes. The study will also investigate the potential sources of contamination and identify areas of concern for groundwater quality management. This study contributes local government officials and legislators in implementing groundwater quality precaution.

KEYWORDS: *Groundwater Quality Index, Chemical Parameters, Water Quality Standards, Geographical Information System, Geogenic & anthropogenic Factors.*

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HIGHLIGHTS

- To assess the distribution of groundwater quality using various physico-chemical parameters using GIS techniques.
- To calculate the groundwater quality index for different sampling locations based on the standard guidelines.
- To integrate GIS tools and remote sensing data for effective groundwater quality identification.
- To determine the potential sources of groundwater contamination co relating with the ground water quality data.
- To raise the awareness of groundwater quality in the study area and do recommend me appropriate mitigation strategies.

GRAPHICAL ABSTRACT

1. INTRODUCTION

Water is nature's most wonderful, and useful compound of the many essential elements for the existence of human beings, animals and plants, water is rated to be of the greatest importance. Without food, human can survive for a number of days, but water is such an essential that without it one cannot survive. Water is not only essential for the lives of animals and plants Groundwater is an important source of water supply throughout the world (Rupal, M., Tanushree, B., & Sukalyan, C. (2012). On the earth, 71% is water but the availability of useable fresh water for drinking and other purposes is about 2.8%. Out of this 2.8 % fresh water, the share of groundwater is only 0.6% that makes it more pertinent to conservation, preservation, and management. Nearly half of all drinking water on the globe comes from groundwater, and 43 percent of all water used for irrigation in agriculture comes from groundwater. Among fresh water sources about 30.10% of water is available as groundwater. So, groundwater is a globally important and valuable renewable resource for human life and the economic development of humans as well as whole countries. In developing countries like India, groundwater contamination has become a serious concern in the post-industrialization era (Vijayakumar et al. 2022).The urbanization, industrialization, and intensive agricultural practices have put further pressure on the available fresh water. The quantity and the suitability of groundwater for human consumption and for irrigation are determined by its physical, chemical and bacteriological properties.

In India, most of the population is dependent on groundwater as the only source of drinking water supply. The groundwater is believed to be comparatively much clean and free from pollution than surface water. In context of quality and quantity, groundwater fluctuates invariably in its own which reflects the time to time status of groundwater as a whole for the region. Ground water which occurs beneath the earth surface is considered free from contamination, hence usable but anthropogenic as well as natural factors are affecting the quality as well as quantity of this valuable resource due to unplanned urbanization and industrialization for the past few decades in few parts of the country. Lack of awareness and civic sense, use of inefficient methods and technology lead to more than 50% of water wastage in the domestic, agriculture & industrial sectors. Water pollution is rendering much of the available water unsafe for consumption.

In the last few decades, there has been a tremendous increase in the demand for fresh water due to rapid growth of population and the accelerated pace of industrialization. Human health is threatened by most of the agricultural development activities particularly in relation to excessive application of fertilizers and unsanitary conditions. Rapid urbanization, especially in developing countries like India, has affected the availability and quality of groundwater due to its overexploitation and improper waste disposal, especially in urban areas. Groundwater pollution occurs when used water is returned to the hydrological cycle (Basavarajappa and Manjunatha, 2015). Groundwater gets contaminated in various ways such as excessive use of fertilizer in farming, seepage from effluent bearing discharge ed from industries, or human intervention. Once the groundwater gets contaminated, its quality cannot be restored by stopping the pollutant from the source in a short period (Sadashivaiah, 2008). Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to device ways and means to protect it. Water quality is characterized on the basis of water parameters (physical, chemical, and microbiological), and human health is at risk if values exceed acceptable limits (BIS, 2012; CPCB, 2013 and WHO, 2012).

The index was first developed by Horton in 1965 to measure water quality by using 10 most regularly used water parameters. The method was subsequently modified by different experts. Water quality index (WQI) is one of the most effective tool to evaluate quality of ground water. In context of the above scenario, the objective of the present study was to analyze the selected water quality parameters of the groundwater in the residential area of Surat City, Gujarat, India to check the suitability mainly for drinking and domestic purposes by WQI value assessment. The WQI has been calculated by using standards of drinking water quality recommended by the World Health Organization (WHO) and Indian Council for Medical Research (ICMR). The weighted Arithmetic index method (Etim et al, 2013 and Brown et al., 1972) has been used for the calculation of WQI in this study. The main benefit of applying water quality indices is the simplification they provide in merging a large number of quality data into a single value, and in presenting an understandable description of quality (e.g., excellent, marginal, poor etc.). Thus, a WQI is an efficient and useful tool to reflect water quality at a sampling site. WQI calculation and Geographic Information System (GIS) has emerged as a powerful tool for storing, analysing and displaying spatial data and these data for decision making in several fields including environment, earth and engineering sciences, urban planning, agriculture, water resources etc. GIS is used as an effective tool for solution for water resources problem for assessing and mapping of groundwater quality (Bind, M. K., & Kanchan, R. (2020).

2. STUDY AREA

2.1. General Features and Topography

Surat district is in the western area of India, in the state of Gujarat. Surat is a very important state of Gujarat with a population of 7.7 million. Surat is the ninth most populated city in India. 'The City Chairman Establishment, a global research organization' focusing on urban issues, ranks Surat fourth in a global survey of the fastest-growing cities. Surat is situated on the banks of the Tapi River, with the Arabian Sea to the west, between latitudes 21°06° N and 21°15° N, and longitudes 72°45° E and 72°54° E. It is 13 meters above sea level. It is a densely populated district of Gujarat state. The district is bound by Bharuch district, in the south by Valsad district, in east by the dang district and Maharashtra state and in a west by Arabian Sea. The coastal part is made of marshy area and consolidated dunes. Prominent rivers include the Kim, the tapi and purna flowing towards the west of the Arabian Sea.The proximity to the sea and low-lying terrain make the groundwater vulnerable to seawater intrusion, resulting in increased salinity and reduced water quality. The tidal fluctuations and seawater ingress into the aquifers further exacerbate the problem, affecting the groundwater's suitability for drinking, agriculture, and industrial uses. Surat district is divided into nine groups of villages, basically we call it a taluka, i.e., Bardoli, Choryasi, Kamrej, Mahuva, Mandvi, Mangrol, Olpad, Palsana and Umarpada, it covers an area of about 4,418 sq. km.

2.2. Temperature and Rainfall

The study area comprises semiarid climate in nature. The summers are hot with temperature ranging from 28°C to 46°C. The climate is temperate during autumn while monsoon is pleasant .The winters are not very cold but the temperature in January range from 19.8°C to 29.8°C. The average annual rainfall in Surat, Gujarat, is approximately 989 mm (38.9 inches), with variations in estimates ranging from 1057 mm to 1143 mm.

2.3. Geology and Soil Type

The surat district geology is characterized by alluvial deposits, including sand, silt, and clay, which are deposited by the Tapi River and its tributaries. Different talukas have distinct soil types, such as Bardoli, Umarpada, Choryasi and Mandvi, are covered by agricultural land and their groundwater may be contaminated by fertilizers and pesticides. Furthermore, because some talukas, such as Palsana and Kamrej, are located along the district's industrial corridor, their groundwater may be impacted by industrial activity and huge sugarcane mills. Industrial waste is also a source of groundwater pollution. Release of industrial waste through the cracks and pores of the earth, groundwater may get polluted. River pollution and toxins from water sediments as well as pesticides and fertilizers enter the groundwater through fractures in the surface of the earth.

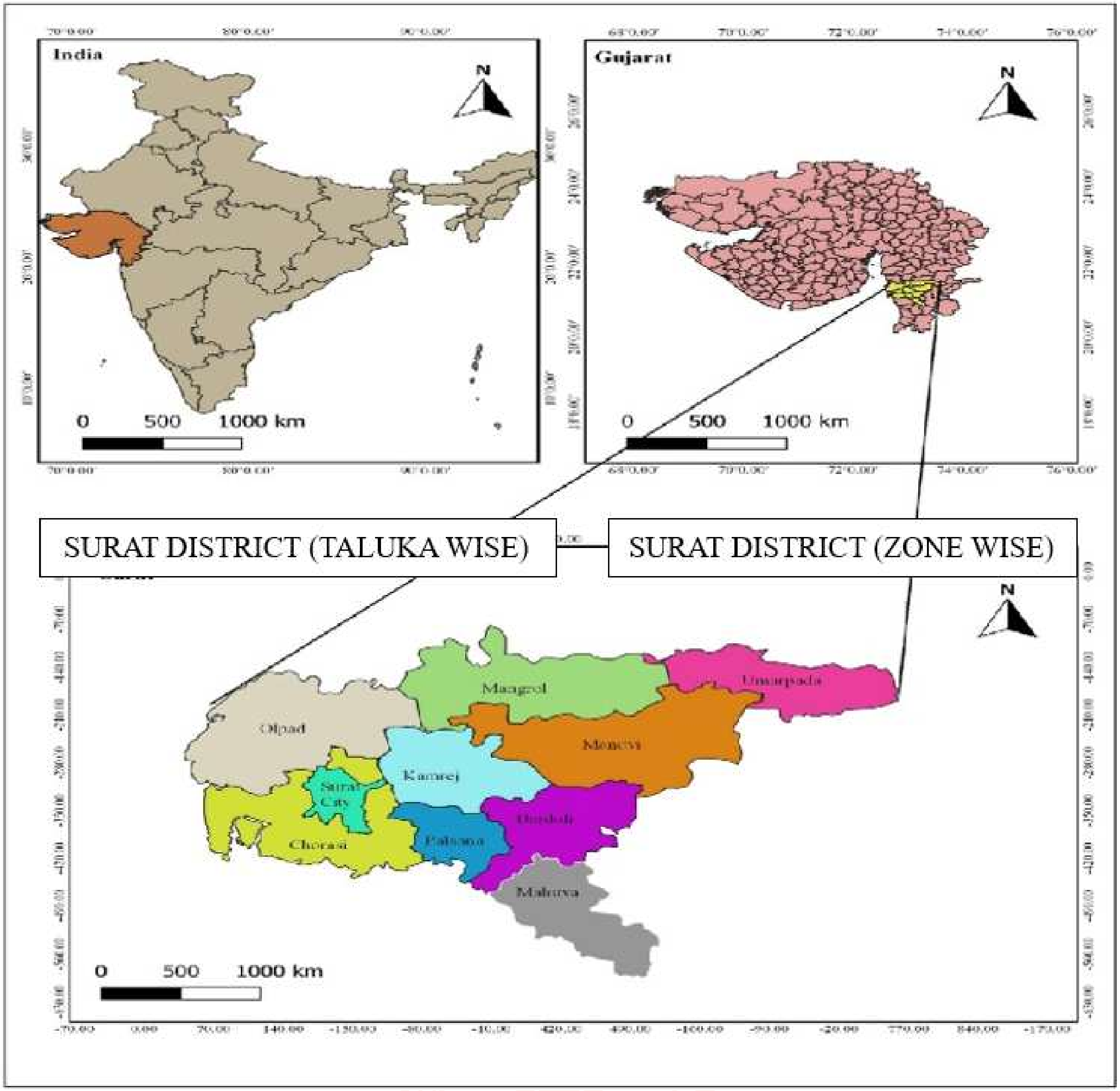

Figure 1. Location of Study Area

3. METHODOLOGY

Water Quality Index (WQI) is considered as the most effective method of measuring water quality. A number of water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of water for drinking. The index was first developed by Horton in 1965 in United States by selecting 10 most commonly used water quality parameters like dissolved oxygen(DO), PH, Coliforms, specific conductance, alkalinity and chloride etc and has been widely applied and accepted in Europe, Africa and Asian countries. The method was subsequently modified by different experts. Furthermore, a new WQI similar to Hortan's index has also been developed by Brown in 1970.

These indices used water quality parameters which vary by number and types. The weights in each parameter are based on its respective standards and the assigned weight indicates the parameter's significance and impacts on the index. A usual WQI method follows three steps which include –

1. Selection of parameters,
2. Determination of quality function for each parameter, and
3. Aggregation through mathematical equation.

Some of the important water quality indices which are generally used

1. Weighted Arithmetic Water Quality Index (WAWQI)
2. Canadian Council of Ministers of the Environment (CCME) WQI
3. National Sanitation Foundation (NSF) WQI
4. Oregon Water Quality Index (OWQI)

Weighted Arithmetic Water Quality Index (WAWQI)

The WQI has been determined using the drinking water quality standard recommended by the World Health Organization (WHO 2017). The Water Quality Index has been calculated using the weighted arithmetic method, which was originally proposed by Horton (1965) and developed by Brown et al. (1972). The weighted arithmetic water quality index (WQI) is represented in the following way:

$$WAWQI = \sum_{i=1}^{n} WiQi = \frac{\sum WiQi}{\sum Wi}$$

Where,
n = number of variables or parameters,
$\mathbf{W_i}$ = unit weight for the ith parameter,
$\mathbf{Q_i}$ = quality rating (sub-index) of the ith water quality parameter.

The unit weight ($\mathbf{W_i}$) of the various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

Wi = K/Sn

where,
$\mathbf{W_i}$ = unit weight for the ith parameter,
$\mathbf{S_n}$ = standard value for ith parameters,
K = proportional constant,

The value of **K** has been considered **'1'** here and is calculated using the mentioned equation below:
K= 1/ Σ(1/Sn)

According to Brown et al. (1972), the value of quality rating or sub-index ($\mathbf{Q_i}$) is calculated using the equation as given below:
Qi=100[(Vo−Vi)/(Sn−Vi)]

Where,
$\mathbf{V_o}$ = Observed value of ith parameter at a given sampling site,
$\mathbf{V_i}$ = Ideal value of ith parameter in pure water,
$\mathbf{S_n}$ = Standard permissible value of ith parameter.

The ideal values (V_i) are taken as zero for drinking water except pH and dissolved oxygen (Tripathy and Sahu 2005). In case of pH, the ideal value is 7.0 (for natural/pure water) while the permissible value is 8.5 (for polluted water). Similarly, for dissolved oxygen, the ideal value is 14.6 mg/L while the standard permissible value for drinking water is 5 mg/L. Therefore, the quality rating for pH and Dissolved Oxygen are calculated from the equations respectively as shown below:

QpH=100 [(VpH−7.0)/(8.5−7.0)]

Qdo=100 [(Vdo14.6)/(5.0−14.6)]

Table 1. Water Quality Rating as per WAWQI Method

WAWQI Value	Rating of Water Quality	Usage Possibilities
0 – 25	Excellent	Drinking, irrigation, industrial
25 – 50	Good	Drinking, irrigation, industrial
50 – 75	Poor	Irrigation, industrial
– 100	Very Poor	Irrigation
>100	Unsuitable for drinking purpose	Proper treatment is required before used

4. RESULT & DISCUSSION

WQI provides a comprehensive, quantitative tool to assess groundwater quality. It supports decision-making for water resource management, especially in areas facing contamination or salinity issues. Integration with GIS enables spatial analysis and mapping of groundwater quality variations. Useful for assessing both drinking water safety and irrigation suitability, critical in arid and semi-arid regions.

The Groundwater Quality Index (GWQI) method offers several advantages:
Simplifies Complex Data: GWQI converts complex water quality data into a single, easy-to-understand index value.

Comparability: GWQI enables comparison of water quality across different locations, time periods, or studies.

Decision-Making: GWQI provides a useful tool for decision-makers to assess groundwater quality and prioritize management actions.

Communication: GWQI facilitates communication of water quality information to stakeholders, including policymakers, managers, and the public.

Identification of Pollution Sources: GWQI can help identify potential pollution sources and prioritize areas for further investigation.

Monitoring and Evaluation: GWQI allows for monitoring and evaluation of groundwater quality over time, enabling assessment of management strategies.

These limitations underscore the need for complementary monitoring tools and region-specific adaptations to ensure accurate water quality evaluations.

Temporal Limitations
GWQIs provide only a snapshot of water quality at the time of sampling, failing to account for long-term trends or seasonal fluctuations caused by agricultural activities, rainfall patterns, or groundwater recharge dynamics.

Parameter Selection and Weighting Issues
WQIs often prioritize specific parameters (e.g., pH, turbidity, nitrates) while omitting others critical to regional contamination profiles. For instance, fecal coliforms may be underrepresented despite posing health risks, leading to misleading "good" ratings. Weighting methods can also skew results, as seen in studies where expanding from 9 to 21 parameters altered outcomes significantly.

Threshold Ambiguity
Categorization into quality classes (e.g., "unsuitable" at WQI 105-185 vs. "excellent" at 17.90) often lacks universal standardization, leading to inconsistent interpretations across studies and regions.

Simplification Risks
By condensing complex data into single numerical values, GWQIs obscure nuanced interactions between parameters. This oversimplification can mask specific health risks, such as fluoride's geogenic contamination being overshadowed by other parameters in aggregate scores.

Lack of Universal Applicability
No single index is universally suitable. For example, the Oregon Water Quality Index (OWQI) classified water as "very poor" in Iraq, while the NSFWQI and Wilcox indices showed better quality in Iran under similar conditions. This inconsistency arises from regional differences in contamination sources, hydrology, and regulatory standards.

Human Activity Oversights
While WQIs detect natural geochemical processes (e.g., Na-HCO_3 water types), they often inadequately reflect rapid industrial or agricultural pollution changes, necessitating supplementary assessments.

Dependence on Local Standards
Indices rely on regional regulatory benchmarks, limiting their transferability. For example, Ecuador's WAWQI and CCMEWQI assessments diverged due to parameter sensitivity differences, highlighting context dependency.

Inadequate Health Risk Representation
Parameters like fluoride or nitrate may exceed safe thresholds without significantly altering overall scores, as seen in studies where "good" WQI ratings coexisted with hazardous fecal coliform levels. This disconnect can obscure direct health threats, particularly to vulnerable groups like infants.

Temporal and Spatial Blindness
WQIs provide snapshots that fail to capture seasonal variations or long-term trends. Agricultural activities, rainfall patterns, and groundwater recharge dynamics can cause fluctuations not reflected in single assessments.

Inflexibility in Application
Traditional GWQIs lack adaptability to regional variations in contamination profiles, hydrogeology, and water-use priorities. While newer models like CCMEWQI address some flexibility issues, most indices struggle to balance standardization with localized needs.

By applying the GWQI method, researchers and practitioners can gain valuable insights into groundwater quality and make informed decisions to protect this vital resource.

5. CONCLUSION

The Ground Water Quality Index (GWQI) method is recognized for its accuracy in assessing groundwater quality because it simplifies complex water quality data into a single, understandable numerical value. The Groundwater Quality Index (GWQI) method is a widely used approach to assess groundwater quality, providing a comprehensive overview of water quality conditions. This method incorporates various physicochemical parameters such as pH, total dissolved solids (TDS), hardness, nitrates, and heavy metals, each assigned a weight based on its relative impact on water quality and human health. The accuracy of the GWQI method lies in its systematic approach, where measured concentrations are compared with standard permissible limits set by agencies like the WHO or BIS. The weighted arithmetic mean technique is commonly used to calculate the index, allowing a balanced reflection of both the presence and severity of contaminants

The accuracy of GWQI is contingent upon several factors, including the selection of relevant parameters, assignment of appropriate weights, and quality of data. When applied correctly, GWQI can offer valuable insights into groundwater quality, facilitating informed decision-making and targeted management actions. However, potential limitations and uncertainties associated with GWQI must be acknowledged, such as spatial and temporal variability, parameter interactions, and subjective weightage assignment. To ensure accurate GWQI assessment, it is essential to follow best practices, including standardized sampling and analysis methods, careful parameter selection, and consideration of local conditions and priorities. By understanding the strengths and limitations of GWQI and adopting a nuanced approach, researchers and practitioners can effectively utilize this method to protect groundwater resources and promote sustainable water management. Additionally, GWQI can be used in conjunction with other tools and techniques, such as geographic information systems (GIS) and multivariate statistical analysis, to provide a more comprehensive understanding of groundwater quality and its spatial distribution.

As a result, the GWQI provides a reliable and comprehensive snapshot of groundwater quality, enabling decision-makers to identify pollution sources, prioritize areas for intervention, and ensure safe water use for drinking and irrigation.

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