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# SPATIOTEMPORALDYNAMICITY OF ENVIRONMENTAL VARIABLES AND WATER QUALITY INDEX IN AQUIFERS AND GROUNDWATER OF BLUE CITY USING MULTIVARIATE STATISTICAL TECHNIQUE

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**ABSTRACT**

Thecurrent research investigates the quality of ten different surface water sites in and around Jodhpur using water quality ratings. This paper gives insight into water pollution's qualitative and quantitative extent. The water quality index (WQI)is usedfor assessing and comparing water quality. In each study region, a five-point grading scale was adopted to classify water quality as a single understandable value. Twelveparameters were employed for determining the WQI of different sites: turbidity, TSS, TDS, conductivity, alkalinity, hardness, calcium, magnesium, chloride, fluoride, and nitrate. Multivariate analysis of the samplesrevealed that most of the individual parameters are not in harmony with the standard values prescribed by the regulating authorities. According to the study, seasonal fluctuations play a significant effect in the hydrochemistry of surface water, indicating a change in WQI. Thesamples showed less pollution in the pre-monsoonseason as compared to post-monsoon. Overall, this paper lays forth a strategy for proper utilization and protection, as well as assesses the quality of surface water to determine its suitability for various uses and its impact on groundwater quality.

Keywords – WQI, Water Parameters, Aquifers, Post-Monsoon, Pre-Monsoon, Spatiotemporal Variations.
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## INTRODUCTION

The blue planet(Earth) is covered with 71% of the water out of which 0.3% of available water is called natural water. There exist three forms of natural water namely; rainwater, surface water, and groundwater.[1] Surface water especially aquifers is the most accessible of the three types. The survival of 144 million of the population is reliant on surface water.[2] Aquifers are ecological barometersthat regulate the micro-climate, maintaining the city's health.[3-4]Aquifers are not only a habitat for a diverse range of organisms but also help in storing freshwater and thereby recharging the groundwater table.[5] Therefore, surface water quality significantly affects groundwater quality because they are directly correlated with each other.[6-7] These aquifers are now facing varying degrees of environmental stress, experiencing a decline in maintaining the state of ecological equilibrium.[8]The deteriorating composition of groundwater and surface water is not only contributed by natural processes like weathering of rocks, erosion, etc. but it also mirrors the anthropogenic activities around it like draining off of untreated industrial and domestic waters, municipal wastes, sewage, immersion of idols, etc. into these reservoirs.[9-11] They may contain organic or inorganic pollutants like heavy metals, phosphates, fluoride, and nitrates that deviates the physiochemical properties of pure water causing water pollution which in turn affects ecosystem as well as human health.[12] These aquifers have fragile ecosystems that, once disrupted, need stringent treatment to make their water consumable. As a result, it is critical to check groundwater quality and design measures to preserve it[13] periodically. Predicting the water quality index is one technique that converts extensive multi-parametric data into a single comprehensible value.[14-15] There are more than 35 WQI models proposed by various scientists/analysts, but the conventionally Weighted Arithmetic method for WQI (WAWQI)is used.[6] Many software


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packages have also been developed, like UNIQ 2008 and QUALIDEX, that determine the overall water quality devised using various analytical parameters.[17-18] The study was performed to determine the water quality index, making it pliant for the citizens, policymakers, and researchers to identify water quality status and thereby make clever strategies to reduce water contamination by reducing anthropogenic activities and urbanization within the sensitive region.[19]

### Study Area and Sampling

The study is predominantly conducted in Jodhpur, Mandore, Shergarh/Hanwantnagar, and Balesar. Ten aquifers were selected from four different stations, and groundwater samples were collected from nearby sites to study the impact of pollution on groundwater due to surface water. The areas chosen for the study are located on the map below.[20 – 21]


Fig.-1: Sampling Sites [https://maps.google.com]

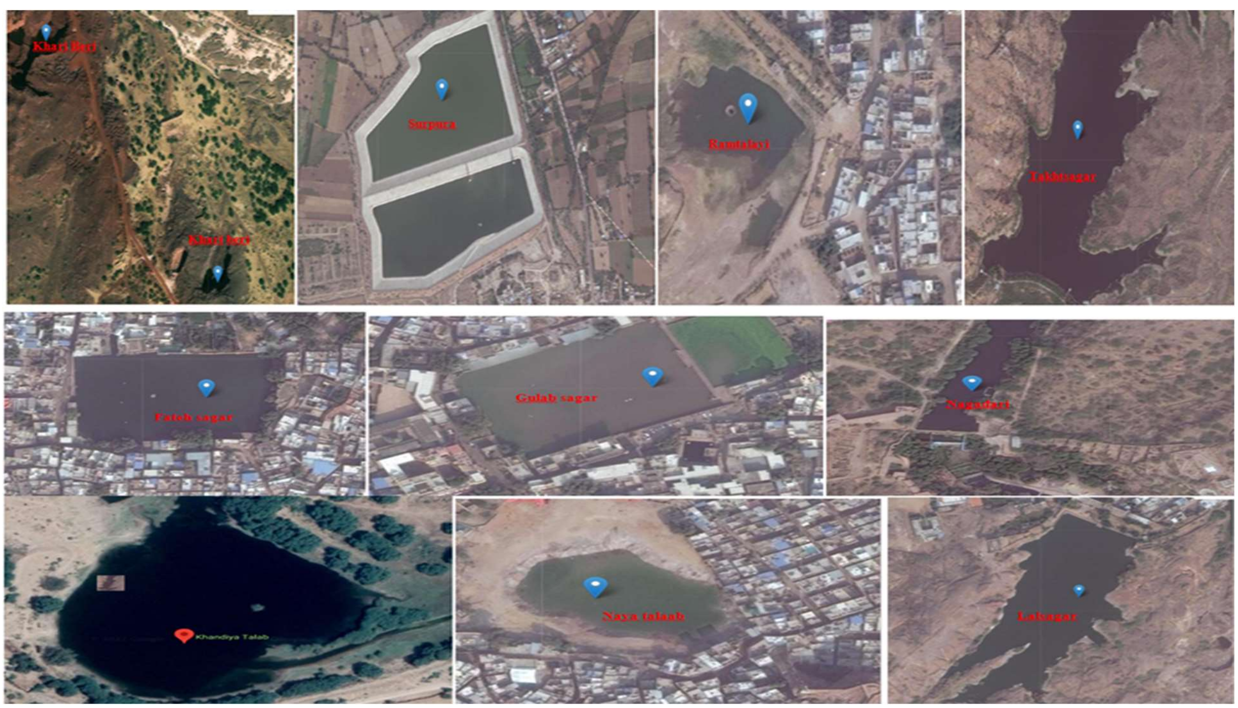


Fig.-2: Geographical Locations of all the Sampling Sites [https://earthexplorer.usgs.gov]

## EXPERIMENTAL

### Sample Collection

To analyze seasonal and spatial fluctuations, 50 samples were collected, including ten surface water samples and forty samples of groundwater from the areas nearby aquifers of the four sampling stations during the pre and post-monsoon seasons. The samples were collected in 1L high-grade HDPE bottles rinsed with 10% HCl, followed by proper washing and rinsing with deionized water several times. Necessary precautions were taken to avoid any contamination from other sources.

### Analyzing Technique/Parameterization of Samples

The collected samples were assessed using standard techniques as prescribed by APHA(1995)to study the following parameters – turbidity (NTU), pH, hardness (ppm),total suspended solids(ppm), total dissolved solids (ppm), electrical conductivity(µmhos/cm), alkalinity (ppm), chloride (ppm), calcium (ppm) and magnesium (ppm) hardness, fluoride (ppm), nitrate (ppm).[22-23]The chemical parameters obtained by analyzing the samples are then subjected to regression analysis. TDS is the independent variable, and all the chemical parameters other than pH and turbidity were treated as dependent variables. Trend analysis used analyzed data to make predictions and anticipate the value of dependent variables. The concentration of any sample parameter can thus easily be measured using a regression model. The WQI is then determined from the perspective of the suitability of water samples for different purposes.[24]

## RESULTS AND DISCUSSION

To analyse parameters of all the samples were verified for the percentage compliance with the standard values as provided by BIS and WHO guidelines are tabulated below:[25-26]

Table-1: Percent Compliance of Parameters with Standard Values

| Parameters | BIS | % Compliance | WHO | % Compliance |
|---|---|---|---|---|
| Turbidity | 5 | 56.7 | 10 | 73.3 |
| pH | 6.5 – 8.5 | 96.7 | 6.5 – 9.2 | 83.3 |
| TSS | 75 | 100.0 | - | 0.0 |
| TDS | 500 | 16.7 | 500 | 33.3 |
| Conduct | 750 | 16.7 | 750 | 63.3 |
| Alkali | 200 | 20.0 | 200 | 93.3 |
| TH | 300 | 3.3 | 300 | 20.0 |
| CaH | 75 | 16.7 | 75 | 43.3 |
| MgH | 30 | 3.3 | 30 | 50.0 |
| Cl | 250 | 53.3 | 200 | 83.3 |
| F | 1 | 53.3 | 1.5 | 73.3 |
| $NO_3$ | 45 | 53.3 | 50 | 53.3 |

From Table-1, it can be observed that most of the samples overseed the desirable limits of the parameters given by BIS and WHO. Regression models were drawn to measure each parameter's contribution by substituting the parameters' average value for pre and post-monsoon season for the sampling stations. Statistical analysis was performed on the data set, and the following values were obtained.[23]

Table-2: Statistical Data of Water Quality Parameters for Samples

| Parameters | Min | Max | AM | SD | CV | Q1 | Med | Q3 |
|---|---|---|---|---|---|---|---|---|
| Turbidity (NTU) | 2.5 | 18.2 | 7.7 | 5.2 | 0.67 | 4.2 | 5.0 | 12 |
| pH | 6.4 | 8.3 | 7.4 | 0.5 | 0.06 | 7.0 | 7.4 | 7.6 |
| TSS (ppm) | 8.6 | 62.3 | 26.5 | 17.9 | 0.67 | 14.2 | 17.0 | 41.1 |
| TDS(ppm) | 208 | 5984 | 2098.6 | 1771.1 | 0.84 | 778.5 | 1320.5 | 3080.0 |
| Conduct. (µS) | 229 | 6582 | 2308.5 | 1948.2 | 0.84 | 856.5 | 1452.5 | 3388.0 |
| Alkali. (ppm) | 70 | 355 | 355.0 | 156.0 | 0.44 | 277.5 | 340.0 | 442.5 |
| TH(ppm) | 273.4 | 2640 | 1285.0 | 720.2 | 0.56 | 688.7 | 1191.4 | 1890.7 |
| CaH(ppm) | 60 | 480 | 233.6 | 123.6 | 0.53 | 115.0 | 116.0 | 117.0 |
| MgH(ppm) | 30 | 440 | 170.4 | 106.6 | 0.63 | 87.5 | 155.0 | 252.5 |
| Cl(ppm) | 28 | 1580 | 467.7 | 497.5 | 1.06 | 90.0 | 225.0 | 680.0 |
| F(ppm) | 0.2 | 5.3 | 1.2 | 1.1 | 0.91 | 0.4 | 1.0 | 1.6 |
| $NO_3$(ppm) | 5 | 432 | 106.8 | 108.7 | 1.02 | 30.5 | 42.5 | 182.5 |

*AM – Arithmetic mean, SD – Standard deviation, CV – coefficient of variation, Q1- Quartile 1, Q3 – Quartile 3

### Turbidity

Turbidity defines the optical clarity of the water as NTU units. Collected samples have the highest value raised from 18.2 NTU before the monsoon period to 19.6 NTU after the monsoon season due to an increase in particulate matter, thereby increasing turbidity values. The lowest turbidity was found at Chopasani in Jodhpur station, and the highest was at Fateh Sagar during the post-monsoon season.

**pH**

The pH is an essential indicator of chemically changing water. Here, the studies show that there is a decrease in pH, from ranging 6.4 to 8.3 in pre-monsoon and 5.9 to 8 in post-monsoon season, indicating an increasing number of materials that decreases pH like plastics, paints or varnishes, municipal wastes, and decreased temperature may also add up as one of the factors for its low values.

**Total Suspended Solids**

TSS defines particles suspended in water that are usually greater than 2 microns. A high concentration of TSS rapidly reduces the aquifer's dissolved oxygen and damages the natural vegetation. The number of suspended particles increased from 62.3 to 67.1 ppm resulting in increased death of fishes in Fateh Sagar Lake.

**Total Dissolved Solids**

TDS measures inorganic and organic substances, such as metals, minerals, salts, and ions that are dissolved in water. Low TDS gives a balanced taste to the water, whereas high TDS indicates harmful contaminants and produces hard water. In our study, TDS ranged from 208 – 6375ppm.

**Conductivity**

EC detects the potentiality of water containing charged particles or ions to conduct electrical current. It is a direct function of TDS. Low values of EC mean high water quality. In our study, the conductivity before immersion ranged from 229 to 6582 µS, which showed a rise from 229 to 7013 µS during the post-monsoon season. This high conductivity may be resulted due to a high amount of chloride.

**Alkalinity**

It is the aggregate of all titrable bases, including bicarbonates, carbonates, hydroxides, borates, phosphates, silicates, and, other commands present.[27-28] Water with high levels of $CaCO_3$ has a high level of alkalinity. The values increased from 760 to 810 ppm due to the high values of all the factors obtained during the post-monsoon period.

**Calcium Hardness**

It refers to the number of dissolved calcium ions in water, making it hard, and causing cardiovascular diseases. The values of calcium hardness range from 60–480 ppm to 60-520 ppm.

**Magnesium Hardness**

In our analysis, the hardness values in water due to magnesium ranged from 30–440 ppm to 30-438 ppm.

**Total Hardness**

It is the magnesium and calcium ion aggregate concentration in water. It is expressed in mg/L as the equivalent of Calcium carbonate per liter.[29]

$CaCO_3/L = 2.497*[Ca] + 4.118*[Mg]$ ppm

In the present study, it ranged from 2640 to 2863, which is attributed to the combining factors of calcium and magnesium hardness. The increase in the hardness of water may be due to seepage, leaching, or soil run-off.

**Chloride**

Chlorides are generally harmless at low levels, but their higher concentration may lead to heart problems and an increase in blood pressure.[30]Our study found that chloride concentration ranged from 28 to 1580 ppm and 30 to 1600 ppm showing a slight rise in its concentration due to sewage contamination or anthropogenic activity.

**Fluoride**

Limited fluoride is recommended in quality water to preserve the enamel from tooth decay, but high fluoride concentrations can lead to skeletal and dental fluorosis.[31] It is between 0.2 to 5.3 ppm during pre-monsoon, and the range is almost the same post-monsoon except for the few places where the concentration is high is may be due to the presence of various factories in that area, especially stone factories, chemical factories, etc.

### Nitrate

Naturally, nitrate is less than one ppm in waterways. High nitrate concentration advances eutrophication and is generally hazardous for human health as it can cause methemoglobinemia, nausea, abdominal cramps, arterial pressure, etc.[32] The lowest concentration of nitrate was recorded in Takht Sagar Lake during the pre-monsoon and in the groundwater sample of Chopasani during the post-monsoon season. The highest tabulated value of nitrate concentration during the pre-monsoon season was 432 ppm, which increased to 445 ppm post-monsoon. It may be due to an increase in anthropogenic activities like festivals dumping of wastes or may be due to seepage through different farm areas or barns. The samples' high coefficient of variance values for chloride, fluoride, and nitrate (Table-2) indicates high water contamination levels. The spider graphs below show the parametric variations in the samples at different sites during the aquifers' pre and post-monsoon season and the sampling stations. It is seen that most of the pieces have high values of TDS and conductance.

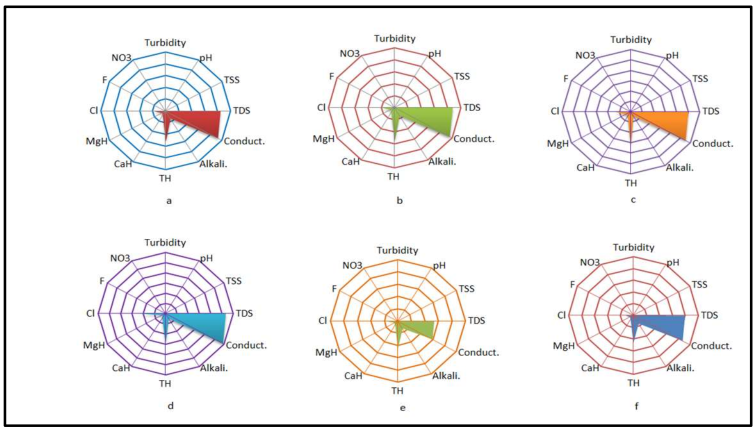
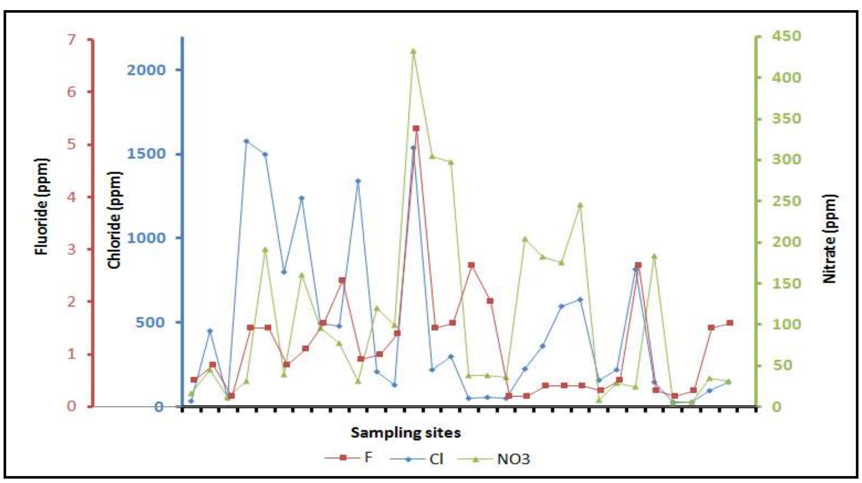



Fig.-1: Spider Charts Showing Spatial Variation in Water Samples (a) Pre-Monsoon (aquifers) (b) Post Monsoon (aquifers) (c)Mandore (d)Balesar (e)Shergarh (f)Jodhpur




Graph-1: Trend of Anions at Sampling Stations

Table-3: Correlation Coefficients of Water Quality Parameters

| | Turbidity | pH | TSS | TDS | Cond. | Alkali | TH | CaH | MgH | Cl | F | $NO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Turbidity | 1. | | | | | | | | | | | |
| pH | -0.609 | 1 | | | | | | | | | | |
| TSS | 1.000 | -0.609 | 1 | | | | | | | | | |
| TDS | 0.516 | -0.407 | 0.516 | 1 | | | | | | | | |
| Conduct. | 0.516 | -0.407 | 0.516 | 1.000 | 1 | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alkali. | 0.548 | -0.649 | 0.548 | 0.628 | 0.628 | 1 | | | | | | |
| TH | 0.540 | -0.278 | 0.539 | 0.833 | 0.833 | 0.457 | 1 | | | | | |
| CaH | 0.624 | -0.312 | 0.624 | 0.793 | 0.793 | 0.513 | 0.947 | 1 | | | | |
| MgH | 0.446 | -0.238 | 0.446 | 0.808 | 0.808 | 0.389 | 0.974 | 0.851 | 1 | | | |
| Cl | -0.018 | 0.344 | -0.018 | 0.574 | 0.574 | 0.059 | 0.684 | 0.615 | 0.690 | 1 | | |
| F | -0.206 | 0.227 | -0.206 | 0.216 | 0.216 | 0.175 | 0.062 | -0.012 | 0.110 | 0.420 | 1 | |
| NO3 | 0.254 | -0.176 | 0.254 | 0.569 | 0.569 | 0.610 | 0.464 | 0.466 | 0.433 | 0.335 | 0.391 | 1 |

Spatiotemporal variation of all the parameters is reflected by Pearson correlation coefficient values (r). The correlation matrix (Table-3) indicates the positive correlation of turbidity with all the parameters except pH, fluoride (post-monsoon), and chloride (pre-monsoon).Turbidity shows maximum correlation with TSS that can be inferred from tables 5 and 6. pH is significantly correlated with only chloride and fluoride. TDS shows a high degree of correlation with conductance having values of 'r' greater than 0.99. Our study observed the highest positive correlation of all the parameters with TDS.

**Water Quality Index**

In the present research, twelve critical parameters are taken for calculating WQI for the collected water samples, and BIS recommended values are taken as standard values.[23]

Table-4: Categorization of WQI and its Intended Uses[23-24]

| Water Quality Index Range | Water Quality Rating | Grade | Possible Uses |
|---|---|---|---|
| 25 - 0 | Excellent | A | Potable, agriculture, and industrial |
| 50 - 26 | Good | B | Potable, agriculture, and industrial |
| 75 - 51 | poor | C | Agriculture and industrial |
| 100 - 76 | Very Poor | D | Agriculture |
| >100 | Inconsumable | E | Prior treatment required |

The water quality index for all the lake samples was calculated separately from the groundwater samples. Thegroundwater samples were classified under four water quality monitoring stations viz Jodhpur, Mandore, Balesar, and Shergarh. After estimating WQI, the values obtained are compared with the standard WQI values, and the water quality is then determined.

Table-5: Standard Water Quality Parameters and Calculation of WQI for site 1 for Pre-Monsoon (Nagadari)

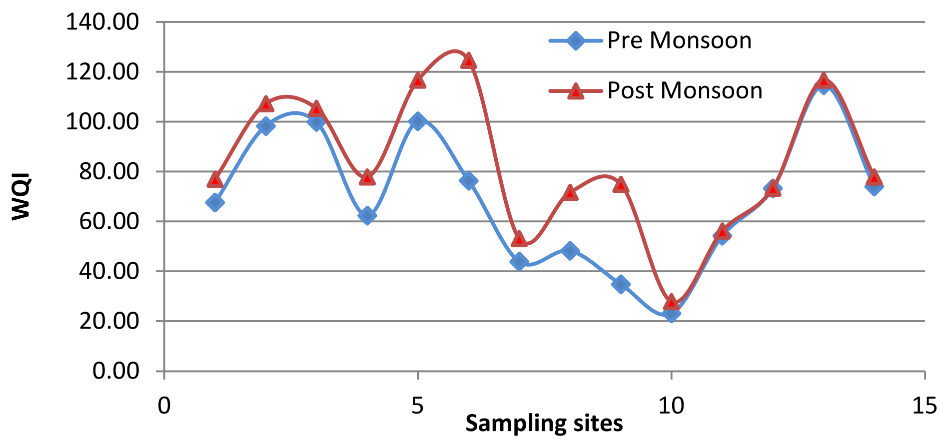
| Parameters | Sn | 1/Sn | ∑1/Sn | K | Win | $V_0$ | Vn | In/Sn | Qn | WnQn |
|---|---|---|---|---|---|---|---|---|---|---|
| Turbidity | 5 | 0.2 | 1.42 | 0.71 | 0.141 | 0 | 17 | 3.4 | 340 | 48.03834 |
| pH | 8.5 | 0.11765 | 1.42 | 0.71 | 0.083 | 7 | 7.2 | 0.13333 | 13.333 | 1.108151 |
| TSS | 75 | 0.01333 | 1.42 | 0.71 | 0.009 | 0 | 58.2 | 0.776 | 77.6 | 0.730936 |
| TDS | 500 | 0.002 | 1.42 | 0.71 | 0.001 | 0 | 750 | 1.5 | 150 | 0.211934 |
| Conduct. | 750 | 0.00133 | 1.42 | 0.71 | 0.001 | 0 | 825 | 1.1 | 110 | 0.103612 |
| Alkali. | 200 | 0.005 | 1.42 | 0.71 | 0.004 | 0 | 370 | 1.85 | 185 | 0.653463 |
| TH | 300 | 0.00333 | 1.42 | 0.71 | 0.002 | 0 | 1557.8 | 5.19267 | 519.27 | 1.22278 |
| CaH | 75 | 0.01333 | 1.42 | 0.71 | 0.009 | 0 | 360 | 4.8 | 480 | 4.521256 |
| MgH | 30 | 0.03333 | 1.42 | 0.71 | 0.024 | 0 | 160 | 5.33333 | 533.33 | 12.55904 |
| Cl | 250 | 0.004 | 1.42 | 0.71 | 0.003 | 0 | 150 | 0.6 | 60 | 0.169547 |
| F | 1 | 1 | 1.42 | 0.71 | 0.706 | 0 | 0.3 | 0.3 | 30 | 21.19339 |
| NO3 | 45 | 0.02222 | 1.42 | 0.71 | 0.016 | 0 | 184 | 4.08889 | 408.89 | 6.419067 |
| ∑ | | 1.41554 | | | 1 | | | | | 96.93152 |
| WQI = 96.93 | | | | | | | | | | |

Similar calculations are performed for the obtained data for all the other sites for post and pre-monsoon durations, and the data obtained are then compared for further analysis. The findings are as follows:

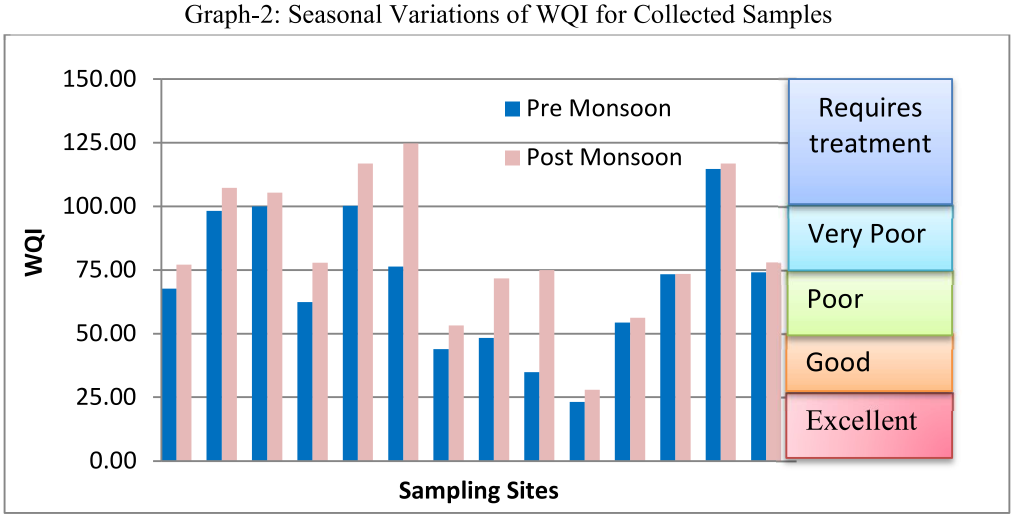
Table-6 Calculated WQI for Collected Samples

| S.No. | Type of Sample | Sampling Sites | WQI | |
|---|---|---|---|---|
| | | | Pre Monsoon | Post Monsoon |
| 1 | Aquifer | Nagadari | 96.93 | 116.07 |
| 2 | Aquifer | Surpura | 98.23 | 107.30 |
| 3 | Aquifer | Lalsagar | 43.90 | 53.16 |
| 4 | Aquifer | Khari Beri | 99.96 | 105.44 |
| 5 | Aquifer | Khandiya Talaab | 89.12 | 109.36 |
| 6 | Aquifer | Naya Talaab | 100.17 | 116.78 |
| 7 | Aquifer | Ram Talayi | 76.35 | 98.72 |
| 8 | Aquifer | Gulab Sagar | 48.32 | 71.72 |
| 9 | Aquifer | Fateh Sagar | 34.92 | 75.00 |
| 10 | Aquifer | Takht Sagar | 23.19 | 27.93 |
| 11 | Groundwater | Mandore | 54.33 | 56.20 |
| 12 | Groundwater | Balesar | 73.33 | 73.39 |
| 13 | Groundwater | Shergarh | 99.96 | 105.44 |
| 14 | Groundwater | Jodhpur | 74.02 | 77.96 |

The WQI values (Table-6) reveal that the samples collected from the aquifers have a significant difference in their WQI values during the pre and post-monsoon period, indicating an increased amount of contamination during the post-monsoon season in the aquifers that may be due to the rise in anthropogenic activities as the samples were collected during that time when most of the festivals take place in India.




Graph-2: Seasonal Variations of WQI for Collected Samples




Graph-3: Spatial Variation of WQI at Different Sites

The calculated results of WQI are drawn to study the effect of spatial and seasonal variations in WQI (graph-2 and3) that stipulate deteriorating water quality during the post-monsoon season. The highest values of WQI were seen at Takht Sagar and Gulab Sagar lakes, as these are the most common sites for dumping waste and for spiritual activities in the city.

## CONCLUSION

WQ index values range from 23.19 to 124.72 in a multivariate study of 50 samples. High WQI scores imply that most parameters' values surpassed the standard / permitted limits. Almost 43.75% of groundwater samples and 79.16% of surface water samples are sub-standard in quality. The overall WQ index of the samples can be categorized under class D, i.e., it can be utilized for irrigation purposes and other purposes only after prior treatment. The study reveals heavy contamination near all the aquifers, which could be attributable to anthropogenic activity, use of chemicals or fertilizers, and the presence of factories or barns near the sites can also be one of reasons for this surface water pollution. Water is associated with the spiritual aspect and is the one that suffers high levels of contamination that consecutively increases chemical parameters of water and simultaneously depletes the quality of water by adding foul color, odor and taste along with water-borne diseases. This polluted surface water, in turn, contaminates the ground water table, which can be seen as a slight variation in WQI values during the pre and post-monsoon period as a result of seepage due to the porosity of the soil. The results also reveal high concentrations of nitrate in the samples, which is alarming as it is detrimental to the health of humans and the aquifers as it is a potential nutrient for eutrophication. Periodical monitoring to determine variation in water parameters and identification of perils of pollution sources is much needed to keep the water sources from tainting, followed by the undertaking of the needful measures. Prior treatment is recommended before consumption at almost all the sampling sites.

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