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Spatio-temporal variations of groundwater by using analysis of variance: A case study in Nashik District, Maharashtra, India

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Abstract

Groundwater is the largest freshwater source in arid and semi-arid regions across the world. Combinations of statistical methods and Geographic Information System (GIS) have been used to evaluate the spatial and temporal changes in hydrochemical parameters of groundwater in Nashik District, Maharashtra, India. Groundwater assessment is based on the hydrochemical parameters of the study area. Water samples were collected from 15 tehsils in Nashik. From each tehsil sixteen water samples were collected having ten well and six bore well samples. All 250 samples were analyzed for hydrochemical parameters such as pH, temperature, electrical conductivity, solids in water, alkalinity ($CaCO3$), carbonate and bicarbonate, chloride, sulphate (SO_4), fluoride (F), total hardness ($CaCO3$), sodium observations were recorded. The aim of this paper is to study seasonal variations graphically and then Analysis of variance (ANOVA) has been performed to study seasonal variation among hydrochemical parameters. Through this ANOVA we have studied the difference between well and bore well samples statistically.

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Introduction

Groundwater is the largest freshwater source in arid and semi-arid regions across the world. Importance of groundwater is further enhanced when subsurface formations consist of hard-rock aquifers. Groundwater in arid and semi-arid areas is an essential domestic, agricultural and industrial source of fresh water. As a result of the rising demand for clean drinking water, management of groundwater quality is a vital task, especially in developing countries. From a strategic point of view, it frequently implies the implementation of control-monitoring studies. The assessment of water quality has an important implication for the groundwater's potential as a resource. It can indicate where negative impacts may be mitigated, also it is possible to conduct an evaluation scheme for the water conservation program. A spatial statistical approach was used to interpolate the data from wells, and to obtain a continuous surface for the analysis that could be used to measure spatial and temporal changes. In addition, GIS has emerged as a powerful tool for handling spatial data and decision making in several areas including engineering and environmental fields. The groundwater level declined considerably in Nashik district. In fact, the groundwater level in Nashik declines every year with the advancement of the non-monsoon season, particularly during summers when surface water sources dry up and groundwater level lowers beyond the economic lift of pumping.

Most dug wells, which constitute the main source of drinking water for rural communities, completely dry up during non-monsoon seasons. Thus, the study area is severely afflicted with water scarcity, which has a direct impact on the livelihood, health, and sanitation of the inhabitants. Unfortunately, no scientific study has been conducted to date in the study area to analyze variability of the groundwater levels. Therefore, in the present study, geostatistics and GIS techniques are integrated to model spatial and temporal variations of groundwater levels to understand the behaviour of the hard-rock aquifer systems. Water deficit and surface water shortage in arid and semi-arid regions have historically necessitated efforts to use groundwater for supplying drinking water and farming in developing countries (Brindha and Elango 2012; Jamshidzadeh and Mirbagheri 2011; Bear *et al.*, 1999). Continued groundwater withdrawals, compounded by a decrease in groundwater recharge, can trigger the Seawater intrusion interface to move inland resulting in additional salinization of the coastal aquifer (de Montety *et al.*, 2008; Kouzana *et al.*, 2009, 2010).

Some researchers have done similar type of work on water quality and spatio temporal variation such as, understanding spatial and temporal patterns of groundwater geochemistry not only requires designing a monitoring network to collect the right data (in terms of data constitutes, collection locations, collection times, etc.) for tackling the problem of interest, but also requires using appropriate statistical methods to extract the spatial and temporal patterns embedded in measurements of groundwater geochemistry parameters. More importantly, hydrogeochemical analysis is needed to understand the natural and anthropogenic factors that control the spatial and temporal patterns of groundwater geochemistry. The recently large variations of groundwater levels over years in many parts of Iran, suggest a precise and detailed study to be undertaken to elucidate the behaviour of groundwater level fluctuations in both, spatial and temporal scales a very useful tool for analysing such processes is geostatistics (Feyereisen *et al.*, 2007; Güler and Thyne, 2004b; Jessen *et al.*, 2017; Rouhani & Wackernagel, 1990). Using cluster analysis together with hydrogeochemical analysis has advanced our understanding on spatial and temporal patterns of groundwater geochemistry. Overexploitation from aquifers to address the irrigation needs, and drought events have caused severe water table level drop in many areas. Where groundwater is used for irrigation, aquifers are also being depleted at an alarming rate (Cloutier *et al.*, 2008; Kim *et al.*, 2003; Nguyen *et al.*, 2015; Shrestha and Kazama, 2007; Simeonov *et al.*, 2003; Wang *et al.*, 2015; Shiati, 1999). Subsequently, hydrogeochemical analysis is conducted for the clusters to investigate spatial and temporal patterns in groundwater geochemistry.

When dealing with spatiotemporal data obtained from a long-term monitoring network, many clustering methods have two limitations on how clusters are classified. One limitation is that cluster classification is conducted only for temporal means (i.e., the means over the entire sampling period) (e.g., Qian *et al*., 2007; Sayemuzzaman *et al*., 2018). While this kind of cluster analysis can help identify spatial patterns, it cannot be used to understand temporal patterns. The other limitation is that cluster classification is conducted separately to data of different sampling times or hydrological conditions (e.g., Hussain *et al*., 2008; Thyne *et al*., 2004).

To our knowledge, there is no study investigating the groundwater quality in the nashik. Therefore, Present study was aimed to investigate the groundwater quality in the Nashik district. Multivariate statistical analysis and GIS-based thematic maps were employed for the investigation of spatial and temporal changes of groundwater quality. Hence, this systematic study was carried out for the first time with the objective of studying the impact of the groundwater quality, identifying the hydrogeochemical processes related to groundwater quality, conducting a hydrochemical evaluation of the aquifer system and delineating the various factors controlling the water chemistry and general suitability of the groundwater for domestic and drinking and agricultural purpose. Therefore, the main objectives of this research work are to determine the spatial variability of groundwater and to identify the root of the pollution that presently affects the groundwater. Therefore, the study was focused on the assessment of water quality based on hydro-geochemical characterization of groundwater. The hydro-geochemical parameters used in the context of groundwater quality and their detailed spatial explanation are distinct from other studies in the literature.

The paper is organized as follows. Materials and methods are discussed in the next section along with study area. Further we have given ANOVA table and graphs of residuals. Finally, conclusions are given.

Materials and methods

Materials

In this paper we have considered fifteen tehsils from the Nashik district. From each tehsil sixteen water samples were collected having ten well and six bore well samples during 2018to 2021, Thus, 250 samples in each season were analyzed for hydrochemical parameters such as pH, temperature, electrical conductivity, solids in water, dissolved oxygen, turbidity, alkalinity (CaCO3), carbonate and bicarbonate, chloride, sulphate (SO_4), fluoride (F), total hardness (CaCO3), sodium, potassium, nitrate, nitrite, ammonia, orthophosphate, total phosphate, boron, aluminum, iron, manganese and silica concentrations and observations were recorded. The concentration levels of hydrochemical parameters indicated the quality of groundwater.

Methods

For the study, we have selected sample using Simple Random Sampling Method by using topography and land use and land cover. In this Paper, seasonal variations are studied graphically and then ANOVA is performed to study seasonal variation among hydrochemical parameters. Through this ANOVA we have studied the difference between well and bore well samples statistically. To study the variations among well and borewell samples as well as seasonal variation, ANOVA has performed on the collected data, which is explained in next section.

Study Area

Most of the Nashik region is located in the Tapi basin, with a small portion in the Godavari basin. It is located between 73°16' and 74°56' east longitude and 19°35' and 20°52' north latitude. It is bordered by the Gujrat state in the northwest, the Dhule locality in the north, the Jalgaon and Aurangabad regions in the east, the Ahmednagar region in the south, and the regions of Thane and Gujrat. According to the 2001 Census, the Nashik region has a land area of 15530 square kilometres and a population of 39,93796. There are 1818 habitable towns there, and 806 of them are ancestral towns (Groundwater Surveys and Development Agency, Government of Maharashtra, Water Supply and Sanitation Department).

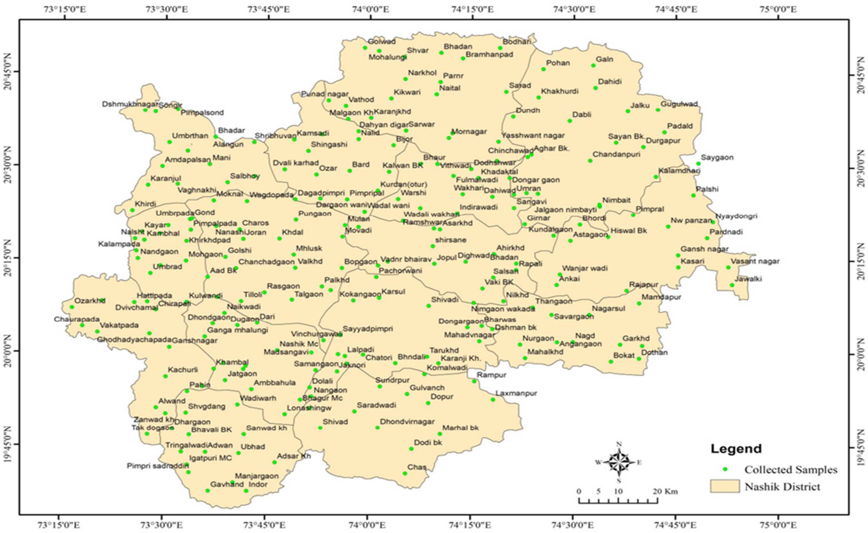

Fig. 1. Map of study area and sample collection points.

In the study area fifteen tehsils around the Nashik district are selected, in which water samples through openwell and borewell are considered. They are Malegaon, Sinnar, Niphad, Baglan, Nandgaon, Dindori, Yeola, Igatpuri, Chandwad, Kalwan Surgana, Trimbakeshwar, Deola, Peinth and Nashik.

Results

To study spatial variation among the parameters ANOVA has been performed. Firstly, assessment and variation of Hydrochemical Parameters has been done graphically. From Fig. 1, it is observed that, pH is increasing from rainy to winter and to summer. There is increasing pattern of pH from well sample to borewell sample there no maximum year wise variation. In Fig. 2, we have seen the variation within sodium season wise and year wise for well as well as borewell samples. Also from fig.2 concentration level of sodium is very high for summer season.

From Fig. 3, concentration level of sulphate is also high in summer. Also observed similarly, we have observed the concentration level of other hydrochemical parameters through graphs. Now, to study the seasonal variation as well as variation within openwell and borewell samples statistically, we have performed two-way ANOVA.

p-value is nothing but the maximum probability of rejecting the null hypothesis that there is significant difference between the average values of hydrochemical parameters of openwell and borewell samples. Likewise, we can say that there is significant seasonal variation for the average values of hydrochemical parameters. From Table 1 it is observed that, for all hydrochemical parameters there is significant seasonable variation, whereas if we look at variation within openwell and borewell samples, it is significant for the average value of sulphate and pH only.

Table 1. Analysis of hydrochemical Parameters to study spatial and temporal variations.

Hydrochemical Parameters	Variation within well and borewell samples				Seasonal Variation			
	Seq SS	Adj SS	Adj MS	p-value	Seq SS	Adj SS	Adj MS	p-value
TDS	105	105	105	0.913	294417	294417	147209	0.000*
Electrical Conductivity	11287	11287	11287	0.138*	313463	313463	156732	0.000*
Chloride	1070	1070	1070	0.718	64614	64614	32307	0.020*
Total Hardness	424	424	424	0.685	118728	118728	59364	0.000*
Bicarbonate	4585	4585	4585	0.140*	120603	120603	60301	0.000*
Alkalinity	950	950	950	0.765	64421	64421	32210	0.049*
Sulphate	5638	5638	5638	0.017*	31890	31890	15945	0.000*
Sodium	58.6	58.6	58.6	0.469	12519	12519	6259	0.000*
Carbonate	79.1	79.1	79.1	0.509	6053	6053	3026	0.000*
pH	50.66	50.66	50.66	0.000*	7.95	7.95	3.98	0.000*

*: significant values for level of significance 0.05

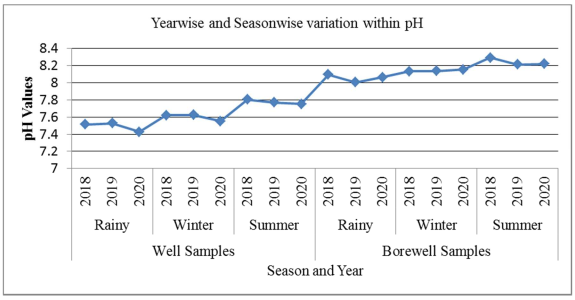

Fig. 1. Variation within pH.

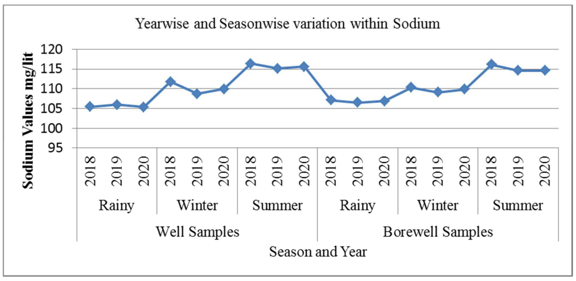

Fig. 2. Variation within Sodium.

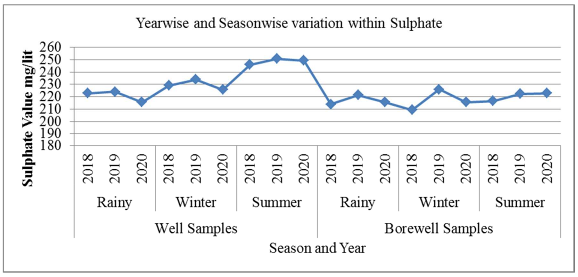

Fig. 3. Variation within Sulphate.

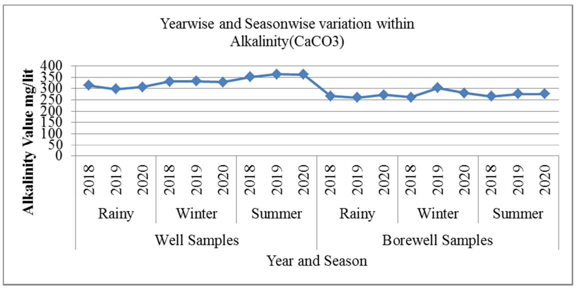

Fig. 4. Variation within Alkalinity (CaCO3).

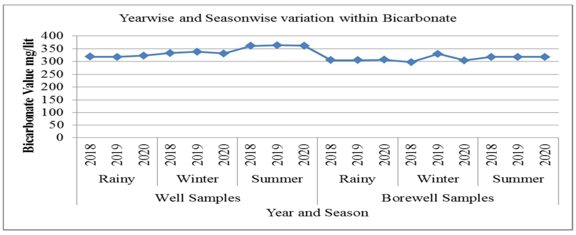

Fig. 5. Variation within Bicarbonate.

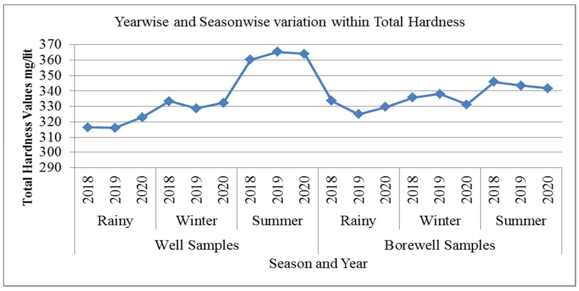

Fig. 6. Variation within Total Hardness.

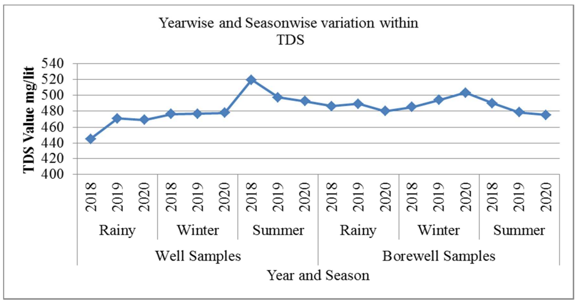

Fig. 7. Variation within TDS.

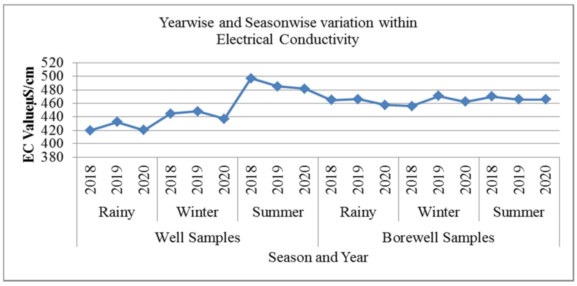

Fig. 8. Variation within Electrical Conductivity.

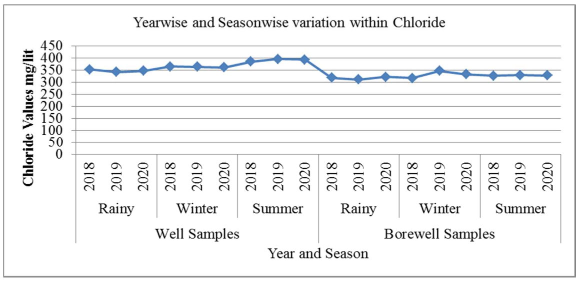

Fig. 9. Variation within Chloride.

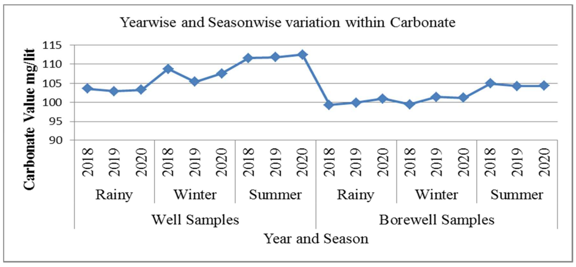

Fig. 10. Variation within Carbonate.

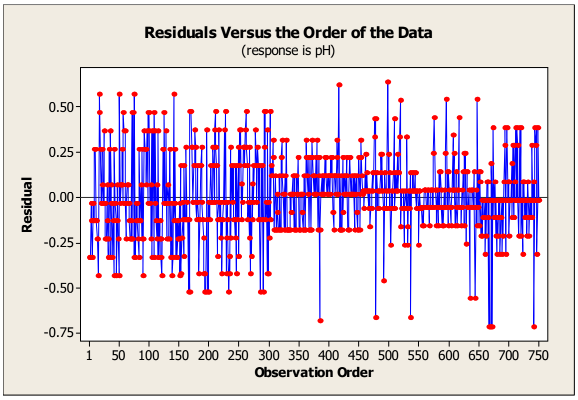

Fig. 11. Response of pH

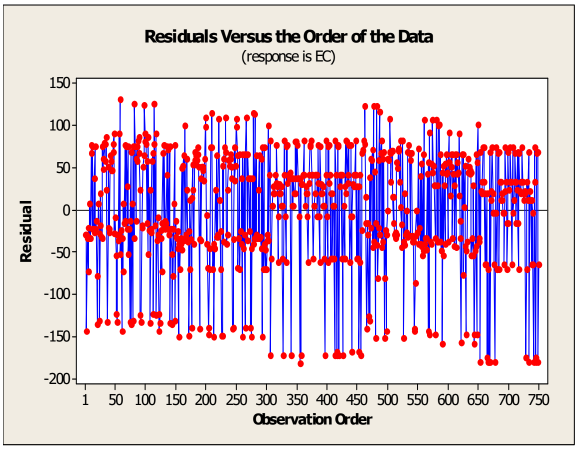

Fig. 12. Response of EC

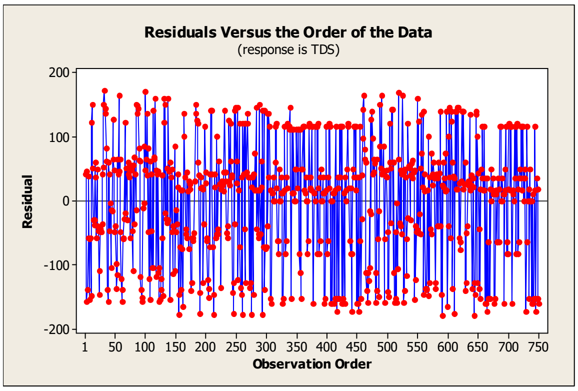

Fig. 13. Response of TDS

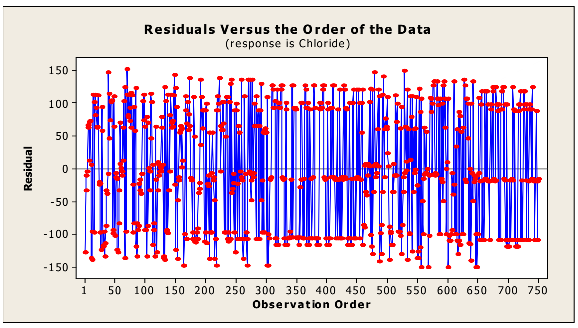

Fig. 14. Response of Cloride

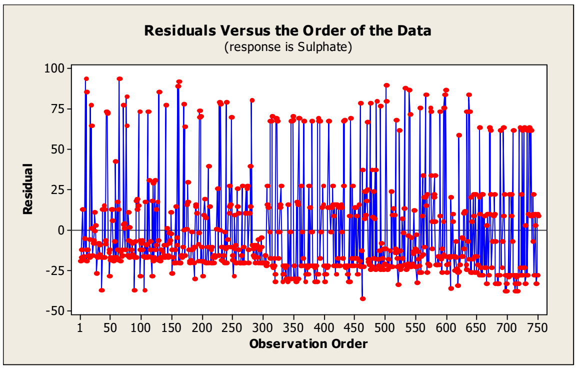

Fig. 15. Response of Sulphate

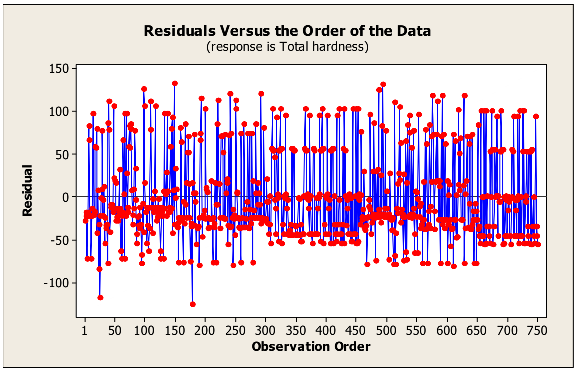

Fig. 16. Response of Total dardness

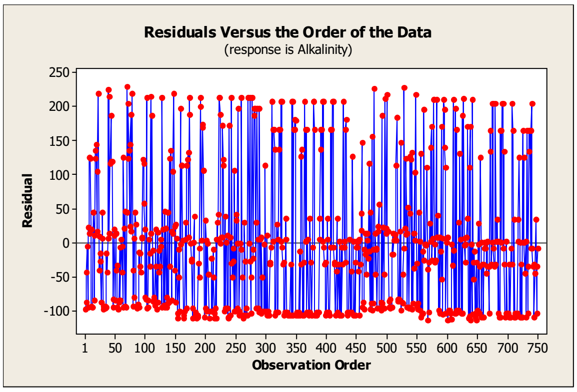

Fig. 17. Response of Alkalinity

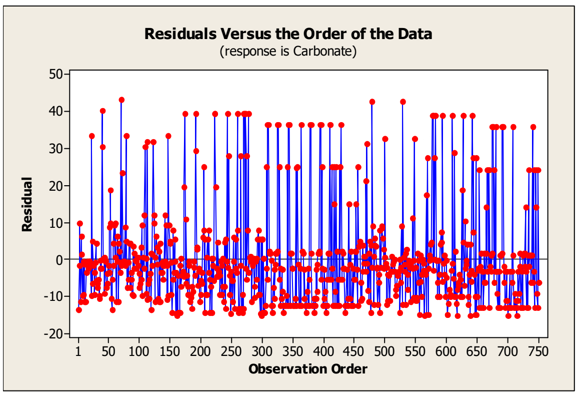

Fig. 18. Response of Carbonate

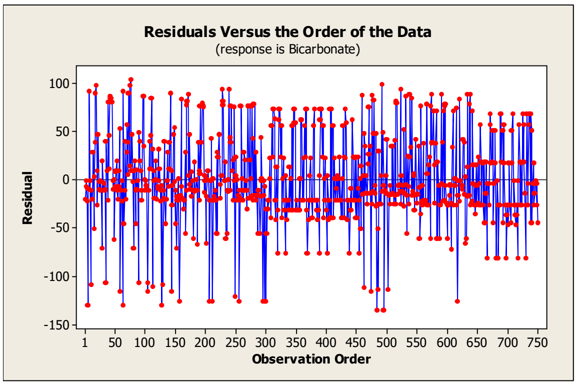

Fig. 19. Response of Bicarbonate

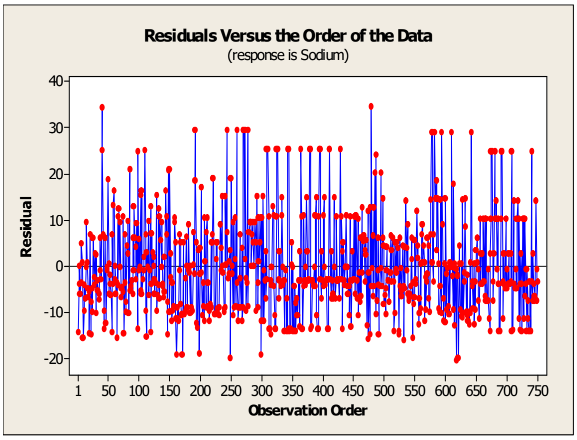

Fig. 20. Response of Sodium

Discussion

Groundwater quality has deteriorated as a result of various geo-environmental hazards brought on by agricultural activities, increased use of fertilisers and pesticides, population growth, rapid industrialization, unplanned urbanisation, failure of the monsoon, and improper management of rainwater in the Ganga Plain. Anthropogenic, agricultural, and natural weathering processes all affect groundwater quality.

It will be easier to determine the quality of groundwater if you are aware of the unique distribution of pH, electrical conductivity (EC), total suspended solids (TDS), fluoride, and total iron concentration. The health of people can frequently be seriously harmed by groundwater contamination. Gastrointestinal diseases like hyperacidity, ulcers, stomach pain, and a burning feeling can be brought on by groundwater with low pH values. Generally speaking, research has shown that groundwater is less polluted than other inland water supplies.

To confirm the notion that the residuals are independent from one another, we use the residuals against order plot.

When exhibited in temporal (seasonal) order, independent residuals do not exhibit any trends or patterns. The patterns in the data may suggest that residuals close to one another are likely connected and therefore not independent. The residuals on the plot should ideally be distributed randomly about the centre line. The pattern structures of residual plots not only aid in validating ANOVA model but also offer suggestions for its enhancement. For instance, a curved pattern in the residual vs. ordered observation plot implies that the fitting model needs to include a higher order component. One can identify a specific type of error term non-independence, known as serial correlation, using residual vs. ordered observation plot. Residuals vs. order graphic aids in determining whether there are any outliers if the data were acquired in a time (or space) sequence.

Conclusions

In this paper, study of seasonal variations is done graphically and then ANOVA is performed to study seasonal variation among hydrochemical parameters. Through this ANOVA we have studied the difference between well and bore well samples statistically. Basic statistics were used in the current investigation to provide early information regarding the water quality data. In Nashik, the quality of the groundwater was examined. Using multivariate statistical analysis, the geographical and temporal change of the groundwater was examined from 2018–19 to 2021 in order to better understand the quality of the groundwater in the study area. The findings demonstrate that Nashik's groundwater quality Spatio-temporal variation is displayed. Additionally, during the past three years, the quality of the groundwater has declined. However, the water quality still complies with national drinking water standards and is fit for agricultural use. Additionally, a multivariate statistical analysis was performed, and the groundwater was successfully classified. This research can be used to develop an ideal sampling plan for the future.

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