Correlation and Regression Model for Physicochemical Quality of Groundwater in the Jaen District of Kano State, Nigeria

Ahmad Abubakar Suleiman[1*], Usman Aliyu Abdullahi[1], Aminu Suleiman[1], Suleiman Abubakar Suleiman[2] & Hassan Umar Abubakar[1]

[1]Department of Statistics, Faculty of Computing and Mathematical Sciences, Kano University of Science and Technology, Wudil 713281, Nigeria

[2]Department of Hydrogeology, Kano State Ministry of Water Resources, Bala Muhammad Road 700221, Kano State, Nigeria

Correspondence: ahmadabubakar31@gmail.com

Abstract

Thirty (30) samples of groundwater from various locations in the district of Jaen were obtained and analysed for drinking and other domestic purposes. Twelve (12) physical and chemical (physicochemical) groundwater quality parameters such as electrical conductivity (EC), pH, total dissolved solid (TDS), total hardness (TH), calcium (Ca), magnesium (Mg), nitrate (NO_3), potassium (K), zinc (Zn), chromium (Cr), copper (Cu) and Manganese (Mn) were selected and analyzed in this study. The conventional remote sensing techniques used for monitoring and estimation of water parameters are typically based on the spectral response or dispersion reflected from the water. An attempt was made in this paper to assess and estimate groundwater elements on the basis of regression analysis. Using a correlation matrix to classify strongly correlated water quality parameters, Pearson's correlation coefficient (r) values are calculated. EC and TDS; Ca and Mg; pH and TH are highly correlated. The results show significant correlation between NO_3 and Zn (r=0.860), TH and Zn (r=0.829), pH and Zn (r=0.808), TH and NO_3 (r=0.732), pH and NO_3 (r=0.686), Cr and Cu (r=0.635), NO_3 and K (r=0.513), TH and K (r=0.500), indicate the increase in the pollution load due to industrial and anthropogenic activities. All physicochemical water variables in this study are significant at 1% and 5% level of significance. Groundwater is suitable for drinking and other domestic uses in the study area with reference to the requirements for the quality of drinking water set out in the Nigerian Industrial Standard NIS and World Health Organization (WHO, 2011). The findings proved the effectiveness of linear regression equations for rapid water quality monitoring and estimation.

Keywords: Correlation coefficients, Drinking, Groundwater, Jaen district, Regression Analysis,

1. Introduction

Water is very important to humans which can be a limiting resource to men and other living organisms. It is difficult to imagine efficient human activity, be it agriculture or livestock, without a well-functioning water source. In every water supply system, the quality of water is as critical as the quantity. Quality of groundwater is the product of all processes and a reaction acting on the water from the moment it is condensed in the atmosphere to the moment it is discharged by a well or spring and varies from place to place and with the depth of the water table (Kana et al., 2014; Henghua et al., 2020). The required quality of groundwater is based on its intended usage. Drinking, bathing, cooking and general sanitation, such as laundry, flushing of closets and other household chores, are the primary purposes for which water is domestically needed.

Three critical factors influencing groundwater quality are the nature of surface run-offs, weathered materials and the mineralogical composition of the underlying rocks. (Anudu et al., 2011). The geology of a region, therefore, plays a very important role in groundwater chemistry. The radical evolution of industrial activities has occurred in recent decades in many urban regions of the world (Basheer et al., 2019), connected to largely successful attempts to increase industrial productivity. Pollution, in general, is regarded as the result of the industrial revolution. The revolution introduced numerous industrial practices that impaired the environmental quality of the area concerned (Emenike et al., 2019; Zhang et al., 2020). The activities also gave birth to different sources of pollution that are necessary for first-hand identification in order to explore the current pollution status in the area.

The level of purity observed in groundwater has decreased dramatically over decades because of so many human activities, such as rapid population growth, agricultural activity, urbanization, precipitation and industrial processes that have increased groundwater to the risk of pollution (Tirkey et al., 2013; Wagh et al., 2018; Adewoyin et al., 2019; Suleiman et al., 2020). Water parameters should be within reasonable limits, such as pH, chloride, total dissolved solid, total alkalinity, calcium, magnesium, total hardness, nitrate and electrical conductivity. The contamination in groundwater may lead to waterborne diseases such as kidney failure, gastroenteritis, maternal and infant mortality, cholera, typhoid fever and giardiasis (Taiwo et al., 2015; Suleiman et al., 2020). Monitoring of water quality parameters is also important because they provide important information for the management of water (Mustapha and Garba, 2015).

To improve the quality of drinking water, different treatment approaches have been introduced. A simpler method based on statistical correlation was developed in recent years using the mathematical relationship to compare water quality parameters (Joshi et al., 2009). It would be an interesting solution for developing relationships between other distinct parameters with convenient and conventionally predictive methods, because traditional chemical analysis is a time-consuming technique. The developed regression equations can be successfully used for parameters with important correlation coefficients to estimate the concentration of certain other components (Saikrishna et al., 2020). The primary aim of this study is to evaluate and estimate the quality of groundwater in the Jaen district through correlation and regression analysis, and the results are analyzed with reference to the quality requirements for drinking water defined by Nigerian Industrial Standard (NIS, 2015) and World Health Organization (WHO, 2011).

Materials and Methods

2.1 Water Samples and Physicochemical Analysis

In this research, in September 2020, 30 representative groundwater samples were collected from different areas in the Jaen district. Groundwater samples were collected in new 100 ml plastic bottles and filtration to extract suspended solids was carried out using filter papers. Afterwards, the samples were carefully sealed and numbered. The collected water samples were analysed using standard methods for key chemical descriptors as follows: electrical conductivity (EC), concentration of hydrogen ions (pH) and total dissolved solids (TDS) were analyzed using the pre-calibrated potable pH-EC-TDS meter in the field. The in-site measurement was necessary because these parameters are likely to change on transit to the laboratory. Also, during the measurement, geographical coordinates were obtained using Global Positioning System (GPS). The remaining parameters (TH, Ca, Mg, NO_3, K, Zn, Cr, Cu and Mn), were determined at the federal ministry of water resources, water quality reference laboratory, Kano. Most of the parameters are expressed in milligram per liter (mg/L), except EC (µS/cm), pH, and TDS (NTU). All computations in this study are carried out using Minitab 14.0 software. Statistical analysis was carried out in respect of physicochemical parameters for all the study sites by calculating Pearson's correlation coefficient (*r*) value and regression equations.

2.2 Correlation Analysis

Correlation is a technique that measures the nature, degree and extent of association existing between two continuous variables. Karl Pearson's correlation coefficient (*r*) is a measure of degree of relationship between two variables ξ and λ (Suleiman et al., 2020), which is expressed as given in Eq. (1).

$$r = \frac{n\left(\sum_{i=1}^{n} \xi_i \lambda_i\right) - \left(\sum_{i=1}^{n} \xi_i\right)\left(\sum_{i=1}^{n} \lambda_i\right)}{\sqrt{\left[n\sum_{i=1}^{n} \xi_i^2 - \left(\sum_{i=1}^{n} \xi_i\right)^2\right] \cdot \left[n\sum_{i=1}^{n} \lambda_i^2 - \left(\sum_{i=1}^{n} \lambda_i\right)^2\right]}} \tag{1}$$

where n is the number of observations. The r values are between -1 and 1; a positive value is indicating positive relationship, while a negative value is a negative association of variables. A value r=0 is an indicator of a negligible relationship between variables (Popoola et al., 2019). Saleem et al. (2012) designated the correlation values as 'moderate' and 'strong', concerning the r values of $0.5 - 0.7$ and > 0.7, respectively. The correlation value ($r < 0.5$) values implies a weak correlation.

This technique was applied to correlate groundwater pollutants in the investigated areas. The correlation of groundwater parameters is computed to identify the contribution amount of association of each parameter contributed to the groundwater contamination (Mejri et al., 2018).

2.3 Linear Regression Model

Developing a strong predictive correlation between the dependent (response) and independent (predictor) variables is the main objective of regression modeling and analysis (Suleiman et al., 2015). If the numerical value of the coefficient of correlation between the two variables is very large, it means that these two variables are strongly correlated. A linear relation is given in Eq. (2).

$$\lambda = A\xi + B \qquad (2)$$

To measure relationship between independent variable (ξ) and dependent variable (λ), the constant A and B can be estimated by fitting the experimental data on the variables ξ and λ through method of least squares. The value of constants A and B are given by the following relations:

$$B = \overline{\lambda} - A\overline{\xi}$$

where $$\overline{\xi} = \frac{\sum_{i=1}^{n} \xi_i}{n} \; ; \quad \overline{\lambda} = \frac{\sum_{i=1}^{n} \xi_i}{n}$$

and $$A = \frac{n\left(\sum_{i=1}^{n} \xi_i \lambda_i\right) - \left(\sum_{i=1}^{n} \xi_i\right)\left(\sum_{i=1}^{n} \lambda_i\right)}{n\sum_{i=1}^{n}\left(\xi_i - \overline{\xi}\right)^2}$$

3. Results and Discussion

The results of the calculated physicochemical parameters of groundwater are given in Table 1 along with the recommended values defined by NIS and WHO for drinking and domestic uses. Comparing with the permissible limits set by NIS (Table 1), 83% of the water samples contain EC within recommended value; pH in 70% of the samples is within allowable limit; TDS in 86% of water samples are within tolerance value; Ca, Mg, NO_3, K, Zn, Cr and Cu contents in all the collected water samples are within acceptable limit recommended by NIS; only 7% of the water samples contain Mn above the recommended value. Therefore, based on the comparison with the guideline set by NIS (2015) and WHO (2011), groundwater of the study area is good for drinking and other domestic uses.

Table 1. List of Physicochemical parameters as determined in groundwater samples from the study area along with the permissible limits set by the NIS and WHO

S/N	Sample Locations	EC	pH	TDS	TH	Ca	Mg	NO_3	K	Zn	Cr	Cu	Mn
1	Unguwar Kashu	654	6.27	330	0.02	1.75	0.74	0.08	0.2	0.12	0	0.08	0
2	Gaida Gidan Gona	514	6.14	259	0.02	0.35	0.15	0.07	0.4	0.03	0	0.14	0
3	Ring Road	626	5.59	315	0.02	0.87	0.37	0.03	0.1	0.01	0	0.1	0.1
4	Shago Tara	796	6.7	402	0.02	0.17	0.07	0.93	0.2	0.7	0.01	0.24	0.1
5	Bakin Diga	902	5.76	456	0.01	0.29	0.12	0.12	0.9	0.01	0.01	0.24	0.2
6	Ajawa	209	6.97	104	0.02	0.07	0.03	0.07	0.5	0.28	0	0.12	0.3
7	Jaen Central Mosque	796	6.65	402	0.02	0.69	0.29	0.21	0.3	0.17	0	0.1	0
8	Saberi	780	6.5	390	0.01	0.26	0.111	0.41	0.3	0.21	0	0.12	0.2
9	Jilawa	234	7.17	118	0.01	0.26	0.11	0.04	0.7	0.05	0	0.1	0.2
10	Mundadu	812	6.97	406	0.03	0.87	0.37	0.11	0.2	0.08	0.01	0.3	0.1
11	Layin Danmarina	998	6.99	499	0.01	0.28	0.12	0.05	0.1	0.17	0	0.08	0
12	Racdo Construction	422	6.9	213	0.01	0.21	0.09	0	0.1	0.07	0	0.08	0.1
13	Panar Ltd	394	6.92	200	0.02	1.44	0.61	0.08	0.1	0.15	0	0.06	0.1
14	Tahir Oil Mills	542	6.82	275	0.02	0.31	0.13	0.4	0.3	0.08	0.01	0.08	0.1
15	Dala Foods	594	6.35	300	0.01	0.36	0.15	0.24	1.3	0.14	0	0.06	0
16	Gidan Taki	422	7.12	213	0.01	0.46	0.19	0.08	0.1	0.12	0	0.1	0
17	Gidan Karfe	326	6.85	165	0.02	0.27	0.11	0.16	0.3	0.1	0	0.08	0.1
18	Dangote Sugar Refinery	446	6.71	226	0.01	0.36	0.15	0.55	0.9	0.08	0	0.08	0
19	Gadar Yanmata	452	6.85	230	0.01	0.24	0.1	0.49	0.4	0.14	0	0.04	0.1
20	Kwanar Nabegu	562	7.22	285	0.03	1.44	0.6	0.02	0.3	0.01	0	0.1	0
21	Ringi	854	6.66	438	0.01	0.21	0.09	0	0.1	0.11	0	0.08	0
22	Housing Estate	306	7.07	151	0.04	1.69	0.71	0.14	0.2	0.01	0.01	0.08	0.1
23	Sabuwar Madina	1003	6.14	524	0.03	0.28	0.12	0.48	0.5	0.12	0.01	0.14	0.2
24	Kwanar Ganduje	356	6.41	179	0.02	0.94	0.4	0.01	0.6	0.14	0	0.06	0.2
25	Sabon Gida	922	6.47	467	0.01	1.32	0.55	0.05	0.2	0.03	0	0.06	0
26	Jigawa	1490	6.32	731	0.01	0.26	0.11	0.24	0.2	0.05	0	0.12	0
27	Makera	1210	6.62	606	0.01	0.33	0.14	0.01	0.1	0.04	0	0.1	0.1
28	Gidan Dagachi	1030	7.2	519	0.02	0.3	0.13	0.55	1.2	0.21	0.01	0.16	0.3
29	Unguwar Lalle	790	6.76	399	0.01	1.1	0.46	0.16	1.2	0.07	0	0.1	0
30	Layin Speaker	740	7.04	374	0.03	0.3	0.22	0.09	0.6	0.13	0	0.14	0.1
	NIS (2015)	1000	6.5-8.5	500	150		0.2	50		3	0.05	1	0.2
	WHO (2011)		6.5-8.5	600		100	50	50	200	0.1	0.05	2	0.1

The minimum and maximum concentrations for potable water of the various physicochemical parameters of the constituents of water quality such as EC, pH, TDS, TH, Ca, Mg, NO_3, K, Zn, Cr, Cu and Mn in the Jaen district are given in Table 2 along with the mean and standard deviations for each parameter. In the study sites, the EC value is in the range of 209 to 1490 µS/cm, indicating high mineralization for drinking purposes. The pH ranges from 5.59 to 7.22, suggesting that the groundwater is acidic to slightly alkaline in nature. The estimated TDS levels were between 104 mg/L in Ajawa and 731 mg/L in Jigawa.

Table 2. Descriptive statistics of groundwater quality variables

	Concentration			
Groundwater Parameter	Minimum value	Maximum value	Mean	Standard deviation
EC	209.0	1490.0	672.7	302.60
Ph	5.59	7.2200	6.6713	0.4114
TDS	104.0	731.0	339.2	151.30
TH	0.0100	0.040	0.0173	0.0083
Ca	0.0700	1.7500	0.5893	0.4964
Mg	0.0300	0.7400	0.2514	0.2076
NO_3	0.0000	0.9300	0.1957	0.2214
K	0.1000	1.3000	0.4200	0.3566
Zn	0.0100	0.7000	0.1210	0.1282
Cr	0.0000	0.0100	0.0023	0.0043
Cu	0.0400	0.3000	0.1111	0.0582
Mn	0.0000	0.3000	0.0900	0.0923

The statistical estimation of the coefficient of correlation between the variables of water quality and the regression analysis provides an indirect means of fast water quality monitoring. However, the dataset is transformed by subtracting mean from each observation before the analyses are carried out. The correlation matrix for the Jaen district for various groundwater quality variables is shown in Tables 3. It is clear that the distribution of calcium, magnesium, and chromium in most of the study areas was significantly associated ($r > 0.5$) with total hardness. The level of significance is taken at 5%. A strongly positive correlation is observed between EC and TDS (0.999) (Figure 1); Ca and Mg (0.972) (Figure 2); pH and TH (0.937) (Figure 3); NO_3 and Zn (0.860); TH and Zn (0.829); pH and Zn (0.808); TH and NO_3 (0.732). The moderately positive correlation coefficient is observed between pH and NO_3 (0.686)(Figure 3); Cr and Cu (0.635); NO_3 and K (0.513); TH and K (0.500). The strong correlation between EC and TDS indicates that the dissolution of salts and the inorganic pollution load in water is attributed to EC (Wagh et al., 2018, Suleiman et al., 2020). However, the positive correlation between the examined water parameters: EC, pH, TDS, TH, NO_3, Ca, Mg, Cu, Cu, Zn and Mn, is an indication that anthropogenic and industrial activities were responsible for contamination of the assessed groundwater parameters in the study area. Therefore, it is inferred that the parameters of water quality correlation studies are of great importance in the study of groundwater.

Table 3. Correlation matrix for water quality parameters.

Parameters	EC	pH	TDS	TH	Ca	Mg	NO_3	K	Zn	Cr	Cu	Mn
EC	1											
pH	.251	1										
TDS	.999	.251	1									
TH	.370	.937	.372	1								
Ca	-.113	.153	-.114	.136	1							
Mg	-.021	.355	.022	.349	.972	1						
NO_3	.377	.686	.382	.732	-.130	.030	1					
K	.161	.453	.166	.500	-.052	.066	.513	1				
Zn	.319	.808	.322	.829	-.081	.105	.860	.407	1			
Cr	.205	.086	.214	.115	.024	.038	.405	.151	.212	1		
Cu	.335	.052	.336	.109	-.167	.127	.257	.110	.258	.635	1	
Mn	-.078	.182	-.074	.189	-.224	-.167	.254	.289	.279	.408	.292	1

Regression analysis was employed in which the parameters of water quality were found to have a stronger and higher degree of significance in their coefficient of correlation. An important parameter in estimating a good fit for the model is the coefficient of determination or simply adjusted R^2 (Suleiman et al., 2020). The adjusted R^2 number of properties makes it a more suitable measure goodness-of-fit than R^2 (Suleiman, 2015). The choice of dependent and independent variables in a regression model is crucial. A simple linear regression approach is used to develop a relationship between EC, pH, TH, Ca, NO_3 and Cr as independent variables and different water quality variables such as TDS, Mg, TH, NO_3 ,K, Zn and Cu as the dependent variable. We report the outcomes for ordinary least squares regressions in the first column in (Table 4). In the second column, we show the values of adjusted R^2. Regression results show that the equations for TDS, Mg, TH, Zn, NO_3, Cu and K significant at 5 % levels of significance. All the regression equations are determined for 30-2= 28 degree of freedom. The significance of the relationship is also confirmed by F-test (Table 4). The p – value given in the third column in (Table 4) is the probability that results could have happened by chance. Since the p – value is less than 5% the derived regression models in this study could be accepted even if R^2 is low (less than 60%).

Table 4. Least square of the relation ($\lambda = A\xi + B$) among significantly correlated parameters.

Regression Equation	Adjusted R^2 value	p – value
$TDS = -0.0000 + 0.5000EC$	99.9%	0.000
$Mg = -0.0000 + 0.4277Ca$	94.3%	0.000
$TH = -0.0000 + 0.2558pH$	87.4%	0.000
$Zn = -0.0000 + 0.6096NO_3$	72.9%	0.000
$Zn = -0.0000 + 0.6068TH$	67.6%	0.000
$Zn = -0.0000 + 0.1615pH$	64.2%	0.000
$NO_3 = 0.0000 + 0.7554TH$	52.0%	0.000
$NO_3 = -0.0000 + 0.1930pH$	45.2%	0.000
$Cu = -0.0000 + 0.8584Cr$	38.2%	0.000
$K = 0.0000 + 0.6493NO_3$	23.7%	0.004
$K = 0.0000 + 0.6518TH$	22.2%	0.005

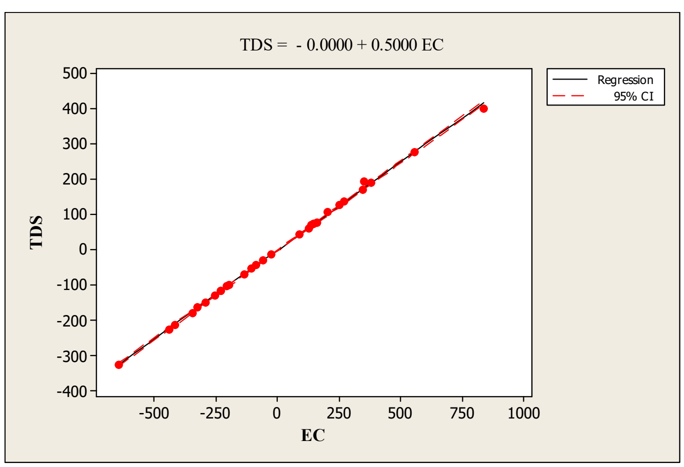

Figure 1. Linear plot between EC and TDS

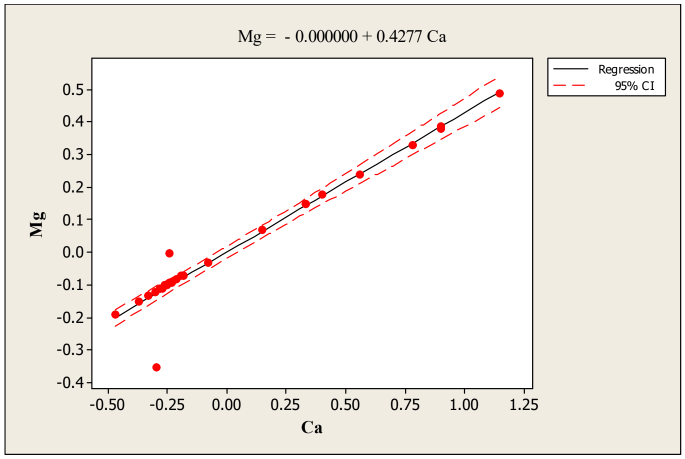

Figure 2. Linear plot between Ca and Mg

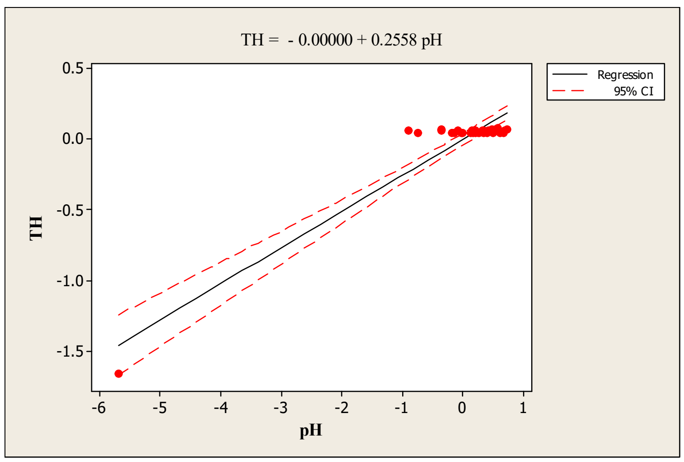

Figure 3. Linear plot between TH and pH

4. Conclusion

This paper analysed the groundwater samples collected in the Jaen district for drinking and other domestic uses based on correlation and regression analysis. Based on the comparison with the recommendation by NIS and WHO, groundwater of the study area is good for drinking and other domestic uses. The linear regression analysis is, however, used for the parameters of water quality and calculates higher levels of significance in its coefficient of correlation. Simple linear regression provides indirect means for the rapid monitoring of water quality. The problems of electrical conductivity and total hardness were found in most of the places in our study area. Electrical conductivity, calcium, pH and nitrate are clearly the most suitable variables that predict or explain 99.9%, 94.3%, 87.4% and 72.9% of the dependent variable parameters in the data set, respectively. This research will be useful for researchers, government and non-governmental organisations to implement successful planning methods and aids for sustainable groundwater management.

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