Nigerian Journal of Technology
Vol. 40, No. 1, January, 2021, pp. 161–167.
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v40i1.21

Simulation of Groundwater Quality Characteristics using Artificial Neural Network

O. O. Fadipe[a,*], L. K. Abidoye[b], J. O. Adeosun[c], B. B. Oguntola[d], O. Adewusi[e], T. E. Okeowo[f]

[a]*Civil Engineering Department, Osun State University, Osogbo, Osun State, NIGERIA.*
[b]*Chemical Engineering Department, Osun State University, Osogbo, Osun State, NIGERIA.*
[c]*Building Engineering Department, Osun State University, Osogbo, Osun State, NIGERIA.*
[d]*Directorate of Works and Physical Planning, Redeemer University, Ede, Osun State, NIGERIA.*
[e]*Osun State Ministry of Water Resources, Osogbo, Osun State, NIGERIA.*
[f]*Osun State Ministry of Works, Osogbo, Osun State, NIGERIA.*

Abstract

This paper reports the study of groundwater quality assessment in Boluwaduro community, Ofatedo in Osun State. In addition, it utilized the Artificial Neural Network (ANN) tool in MATLAB Software to simulate the water quality parameters/contaminants. Water samples were taken from 18 randomly selected dugwells and subjected to physico-chemicals and microbiological analysis. The mean concentrations of nitrate, nitrite, lead and iron are 20.12 mg/L, 0.78 mg/L, 0.159 mg/L and 0.35 mg/L respectively. Total plate counts range between 27 – 96 cfu/mL with growth in all the water samples. The ANN structure was trained in several rounds till satisfactory output was obtained with correlation value of R^2 = 0.97. Simulation of the pH using ANN provides a good match at 10% increment of chloride, nitrate and iron and the pH value of the water sources increased with the corresponding increase in the concentrations of the parameters. The generated model for TDS gave a good prediction with total hardness and magnesium respectively. The concentrations of some metals in the wells are not safe for drinking; it could pose danger to users of the water sources. It is therefore recommended that the wells in the community should be subjected to routine monitoring and treatment of the contaminants should be enforced.

Keywords: water quality, dug wells, ANN, physico-chemical characteristics, microbiological characteristics

1. INTRODUCTION

Groundwater is a viable source of drinking water and its use in augmenting inconsistent pipe-borne water in Osun State is high. It has played a fundamental but often unappreciated role in the social well-being of most communities [1]. In most cases, it is used without treatment as it is believed that the ground has natural filtration capacity and mechanisms for removal of particulate matter, dissolved chemicals and gases. Groundwater is prone to pollution from human activities because water is an excellent solvent and since it has a lot of opportunity to dissolve substances as it moves through rocks and subsurface soil, it can contain lots of dissolved chemicals. The quality of groundwater sources is affected by the characteristics of the media through which the water passes on its way to groundwater zone of saturation [2].

The composition of groundwater is used to determine its potability and serves as a tool for determining the sources of naturally occurring and human related contaminants. Groundwater contains seven major chemical element ions such as Calcium (Ca), Magnesium (Mg), Chloride (Cl), Bicarbonate (HCO_3), sodium (Na), potassium (K), sulphate (SO_4) and these play a significant role in classifying and assessing the groundwater quality. Potable water is one that can be used for drinking purposes with safety and satisfaction [3]. Potable or water of good quality is of vital concern to mankind since it is directly linked with human welfare [4]. It has been reported that the most common groundwater-quality problem in rural water supplies is bacterial contamination from septic tanks, which are often used in rural areas that do not have a sewage-treatment system. The occurrence and percentage distribution of the microbial characteristics is very high in wells around a dumpsite suggesting contamination from the leachate [5]. As groundwater flows

*Corresponding author (**Tel:** +234 (0)803 453 9764)
Email addresses: olayemifadipe@yahoo.com (O. O. Fadipe), kluqman2002@yahoo.co.uk (L. K. Abidoye), julianah.adeosun@uniosun.edu.ng (J. O. Adeosun), oguntolab@run.edu.ng (B. B. Oguntola), oyebolaadewusi@gmail.com (O. Adewusi), titilayookeowo8@gmail.com (T. E. Okeowo)

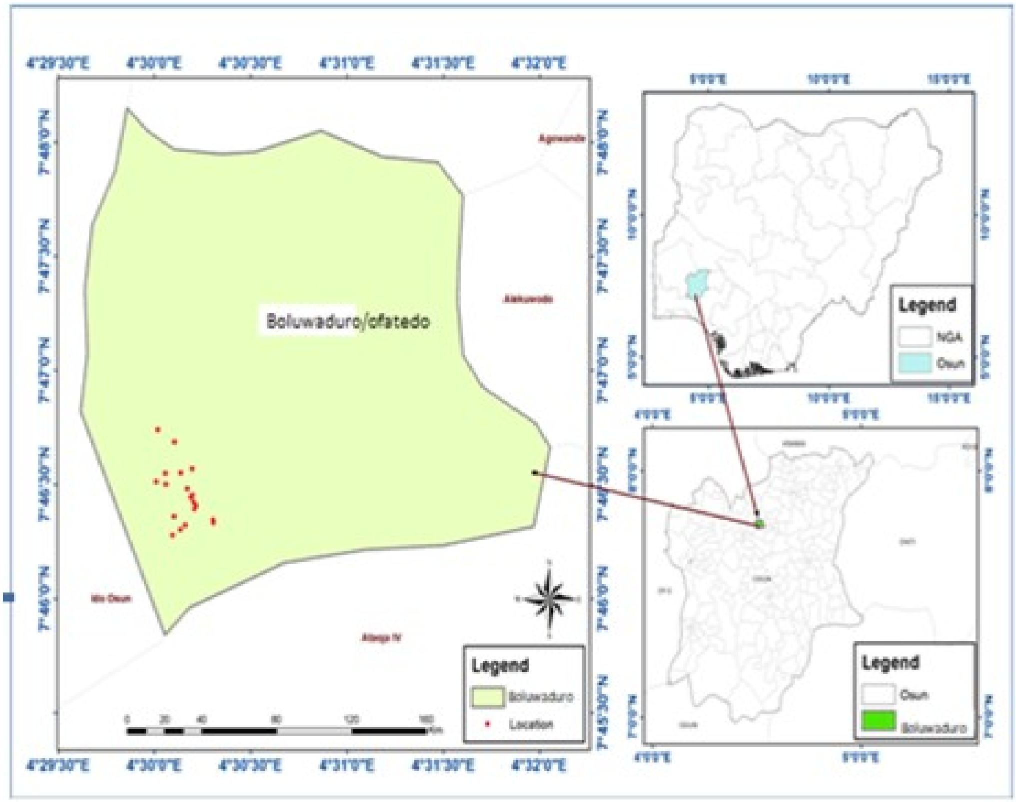


Figure 1: Study Area Map with Sampling Points.

through sediments, heavy metals such as iron, manganese, arsenic, lead etc are dissolved and may later be found in high concentrations in water. The main factors that make groundwater vulnerable as analysed by [6] revealed that soil characteristics and filtration capacity promote or hinder the diffusion of environmental contaminants. The chemistry of groundwater is controlled by the type of geological materials through which the water flows and the amount of time the water is in contact with these materials. Urbanization affects the quantity and quality of groundwater [7] by radically changing the pattern and rates of recharge initiating new abstraction regimes, and advently affecting groundwater quality.

Chemical contamination of drinking water may have effects on health, although in general, these tend to be chronic rather than acute, unless a specific pollution event has occurred and are therefore generally considered of lower priority than microbiological contamination [8]. Potable water helps to decrease mortality and morbidity rate in women, children and infants.

Assessing groundwater quality is very crucial for maintenance and sustainability of the source. A lot of statistical tools have been employed for water quality assessment such as Geographical Information System (GIS), Groundwater Quality Index (GQI), DRASTIC [9], Multivariate analysis (principal component, cluster analysis) [5], Water Quality Index (WQI) [10]. However, when there is a complex non- linear relationship and uncertainty between the parameters of ground water quality, Artificial Neural Network (ANN) has become a popular method in prediction because they can overcome some of the difficulties associated with traditional statistical approaches. ANN model is a conceptual model and it is a simplified image of the mathematical model. Unlike physically based numerical models, ANNs do not require explicit characterization and quantification of physical properties and conditions of the system under investigation. ANN learns the systems behaviour from representative data. The key advantages of ANN are that it has the ability to learn and model non-linear and complex relationships, which are really important because in real-life, many of the relationships between inputs and outputs are non-linear as well as complex. Groundwater assessment should be conducted on routine basis because factors contributing to quality are time dependent on several factors. Using instrumentation in analysis is most times subjected to errors and titrimetric procedures take longer, hence simulating some parameters could give a quick response. Potable water supply to the study area is irregular, thus residents use dugwells to augment drinking water. This paper presents the result of groundwater quality for potability assessment and also simulates some parameters which are useful for predicting the quality of the dugwells in response to changes in concentrations.

Table 1: Coordinates of well points.

Well No	Easting (m)	Northing(m)	Elevation (m)	Apparent colour
1	4.503595	7.773480	294.40	Colourless
2	4.503371	7.773716	292.40	Colourless
3	4.503455	7.772210	291.80	Colourless
4	4.449849	7.779220	308.00	Colourless
5	4.503340	7.774218	310.60	Colourless
6	4.503150	7.774096	296.78	Light brown
7	4.502846	7.774693	289.40	Colourless
8	4.503268	7.776145	302.90	Colourless
9	4.502271	7.775845	301.60	Colourless
10	4.501720	7.778095	308.90	Colourless
11	4.501685	7.772680	303.70	Colourless
12	4.501001	7.775025	303.50	Colourless
13	4.500946	7.775821	304.80	Colourless
14	4.500146	7.775211	304.80	Colourless
15	4.500277	7.778988	284.90	Colourless
16	4.505092	7.772203	302.60	Colourless
17	4.505081	7.772403	304.00	Colourless
18	4.502630	7.772028	305.20	Colourless

Table 2: Descriptive Statistics of Physical Parameters.

Parameters N = 36	Min	Max	Mean	Std dev	Kurtosis	skewness	WHO
Turbidity	1.130	7.41	2.85	1.36	3.54	1.70	5.0 NTU
Temperature	26	28.5	27.0	0.61	0.11	0.55	26
EC	143	424	264.83	76.22	0.56	0.37	1000
Ph	6.55	7.71	6.94	0.24	2.16	0.89	6.5-85
TDS	94	281.3	171.39	44.65	0.03	0.48	500

2. METHODOLOGY

2.1. Study Area

The study area (Fig. 1) is Boluwaduro Community, Ofatedo Area in Egbedore Local Government, Osogbo, Osun State, located along coordinates 7°46'00"N and 4°29'30"E to 7°48'00"N and 4°32'00"E.

2.2. Sampling Points

A total number of eighteen randomly selected dugwells wells (Table 1) within Boluwaduro community were used for the assessment. A GPS device was used to take the coordinates and it was imported into the study area map using ArcGIS 10.1. Before sampling commenced, the depth of each of the wells and the depth to water levels were measured. Water sampling was carried out twice to cover the rainy and dry season. The water samples were collected in prewashed 1L white kegs and were labeled accordingly.

They were transported to the laboratory in ice packs and were analysed within 24 hrs. Physical parameters such as turbidity, temperature, colour, TDS, conductivity, and dissolved oxygen were analyzed using hand held meters on-site and laboratory meters for verification. Chemical and heavy metal characteristics (total alkalinity (TA), total hardness(TH), Mg, SO_4, NO_3-N, NO_2, Cl, HCO_3, CO_3, Fe, Cr, Mn, Pb, Zn, Cu and As) were analyzed using a combination of titrimetric and instrumentation (Palintest Photometer 5000) at the water laboratory of Osun State Water Corporation. The multiple tube fermentation technique was used for the microbiological analysis

2.3. Statistics and ANN Modeling

The results of the analysis were subjected to descriptive statistics and ANN modeling and simulation. The ANN tool of the MATLAB software was used to model the input to output relations. The modeling technique entails different configuration that was chosen and trained till the desired outputs became satisfactory.

3. RESULTS AND DISCUSSION

3.1. Descriptive Statistics

The physical analysis (Tables 2) showed that the results compared well with the WHO standards except for well no 6 (Table 1) that has turbidity value of 7.41 NTU as against 5 NTU permissible values. Often, turbidity is associated with groundwater when small particles are suspended in the water and it scatters and absorbs light rays: this gives the water a murky or turbid appearance. Clay, silt, tiny fragments of organic matter and microscopic organisms are some of the substances that can cause turbidity and they occur in water naturally or because of human activities and pollution. Turbidity is very important in drinking water quality because suspended particles can provide hiding place for harmful microorganism; there by shielding them from disinfection process in a water treatment.

Table 3: Descriptive Statistics of Physical Parameters.

Parameters (mg/L)	Min	Max	Mean	Std Error	Kurtosis	Skewness	WHO
TA	104.100	312.00	194.170	53.470	-0.270	0.480	200.00
DO	1.560	4.520	3.040	0.780	-0.870	-0.020	4.000
TH	96.000	268.000	189.506	38.070	0.300	0.030	100.000
Mg	1.500	30.500	14.700	6.620	0.160	0.120	10.000
NO_3-N	10.000	55.500	18.620	9.040	9.050	2.870	10.000
SO_4	20.000	34.000	25.770	4.520	-1.410	0.280	250.000
Cl	3.500	46.510	16.360	9.310	2.220	1.330	250.000
NO2-N	0.070	2.100	0.770	0.330	7.210	1.660	0.100
HCO3	24.000	122.500	69.900	33.210	-1.390	0.120	1.000
CO3	94.000	346.000	195.000	61.560	-.010	0.790	0.100

Table 4: Descriptive Statistics of Heavy Metals.

Parameters	Min	Max	Mean	Std Error	Kurtosis	Skewness	WHO
Fe	0.045	2.190	0.680	36.440	35.990	5.990	0.300
Cu	0.000	0.880	0.110	0.250	3.550	2.210	10.00
Mn	0.000	0.0040	0.0010	0.001	0.070	0.990	0.200
Zn	0.000	0.440	0.020	0.070	31.510	5.480	5.000
Pb	0.000	0.021	0.010	0.010	-0.970	0.570	0.010
Cr	0.000	0.020	0.0030	0.004	2.330	1.650	0.050

Table 5: Results of Microbiological analysis.

No of wells	Total plate count cfu/ml	Total coliform MPN/ml	E.coli cfu/ml	No of wells	Total plate count cfu/ml	Total coliform MPN/ml	E.coli cfu/ml
1	58	3	Growth	1	76	3	Growth
2	62	8	Growth	2	45	8	Growth
3	84	4	Growth	3	92	4	Growth
4	96	7	Growth	4	84	7	Growth
5	27	5	Growth	5	32	3	Growth
6	75	4	Growth	6	82	6	Growth
7	46	16	Growth	7	44	13	Growth
8	64	4	Growth	8	62	10	Growth
9	56	11	Growth	9	60	10	Growth
10	54	6	Growth	10	52	8	Growth
11	63	6	Growth	11	60	8	Growth
12	54	12	Growth	12	52	11	Growth
13	76	14	Growth	13	78	15	Growth
14	85	16	Growth	14	82	12	Growth
15	64	7	Growth	15	60	8	Growth
16	72	5	Growth	16	70	8	Growth
17	56	4	Growth	17	59	3	Growth
18	48	2	Growth		52	6	Growth

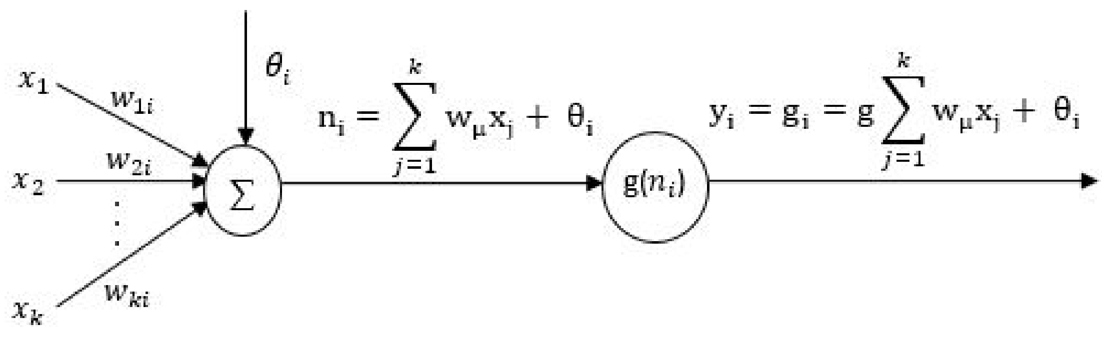


Figure 2: Typical Operation Around a Single Neuron in MLP Network.

Drinking water that is not adequately disinfected can cause diseases in humans [11]. The temperatures of some of the water samples were higher than the WHO standards. Water with high temperature can lower the solubility of oxygen dissolved in it making such water to taste flat. The chemical characteristics and the heavy metals (Tables 3 and 4) revealed that all the parameters were within WHO standards except NO_3-N , NO_2-N, Fe and Pb . All the wells have nitrates values that were higher than the permissible; the mean and the maximum values (18.62 mg/L, 55.5mg/L) of NO_3-N were too high and consumers of water of these wells are at risk of nitrate induced symptoms.

The sources of high concentrations of nitrate are mostly anthropogenic, particularly indiscriminate waste disposal and agricultural practices [12]. When nitrate in groundwater (as an equivalent of nitrogen e.g NO_3-N) is less than 0.2mg/L, it denotes natural or background level, 0.21-3.0 mg/L represent a transition between natural and human influence and 3.1 -10.0 mg/L are interpreted to indicate possible human influences [13]. The layout of most septic tanks and dugwells are not properly regulated in most cities of Nigeria, thus contamination from sewage is always possible. When groundwater is contaminated with sewage, most of the nitrogen is originally present in form of complex organic molecules which are eventually broken down by microbes to form nitrites and nitrates. In addition, nitrates can enter groundwater from chemical fertilizers used in agricultural areas. Excessive concentrations of nitrates and nitrites in drinking water pose an immediate and serious threat to infants under 3 months of age. The nitrates ions react with the blood haemoglobin, reducing the bloods ability to carry oxygen and this produces a disease called blue baby or methemoglobinemia [11]. The concentrations of the heavy metals were within the permissible values but the maximum values (0.21 mg/L) of Pb (wells no 4, 9 and 14) were higher than the 0.01 mg/L permissible limit. Lead is a commutative poison and a possible carcinogene. Excessive lead intake may cause the development of auto –immunity in which a person's immune systems attack its own cells which can lead to joint disease [14].

The concentration of Fe is high; a situation which has been reported in most groundwater in the basement complex of Nigeria [15]. Iron occurs naturally in soils and rocks because in most aquifers, groundwater comes in contact with this solid material, dissolving them. Usually iron is less than 0.5 mg/L in fully aerated water while groundwater with pH less than 8 can contains 10 mg/L; infrequently, 50 mg/L may be present. Excess level in domestic water supplies are connected with staining of clothes and utensils, blackening of food and bitter taste, while overload in the body is linked to hemochromatosis, a genetic disorder which causes diabetes, impotence and liver failure [16].

The presence of microorganisms in groundwater is heavily dependent upon geologic conditions such as flow pathways and mechanisms, sunlight, temperature, pH, and soil properties. All the water samples showed growth (Table 5), suggesting that drinking the water may trigger any water borne diseases if not treated before consumption.

3.2. Simulation

This study utilized a multilayer perception (MLP) which has elements called neurons that are grouped into input, hidden and output layers with respective biases, weights and transfer functions. Figure 2 showed a summation (∑) and a nonlinear activation or transfer function (g). The common activation functions in use are the hyperbolic tangent (tanh) and sigmoid function [17]. The hyperbolic tangent (tanh) function is as shown in Eq. (1).

$$\tanh(x) = \frac{1-\exp^{-x}}{1+\exp^{-x}} \tag{1}$$

While the expressions for Tangent-Sigmoid (TanSig) and Log-Sigmoid transfer functions are shown in Eq. (2) and (3):

$$\text{tansig}(x) = \frac{2}{1+\exp(-2x)-1} \tag{2}$$

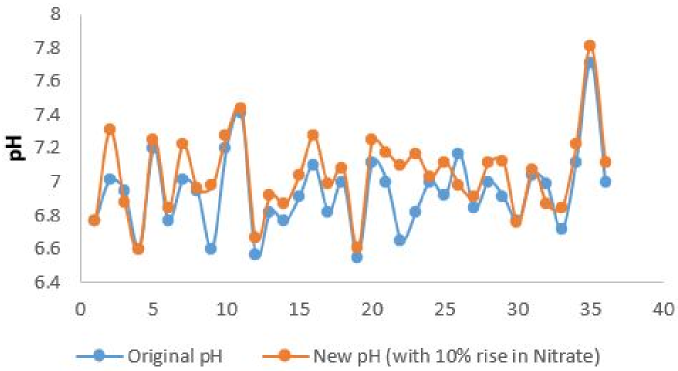
$$\text{tansig}(x) = \frac{1}{1+\exp(-x)} \tag{3}$$

The Tangent-Sigmoid (*tansig*) transfer function was used as the hidden layer while the linear transfer function-purling, was used at the output layer. Equation 4 gives the output of neuron, i, after the activation function,

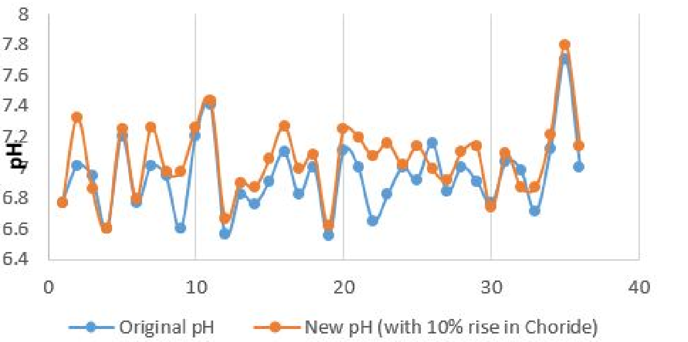
$$y_i = g_i = g(\sum_{j=1}^{k} w_{ji}x_j + \theta_i) \tag{4}$$

The inputs to the neuron, i, are x_k, where $k = 1,\ldots,K$. In this study, x are the parameters (physico-chemical and heavy metals) and w are the different weights assigned to each parameters by ANN. The inputs are multiplied by weights, w_{ki} and are then summed up together with a bias term, θ_i, which is a constant for each neuron. The ANN structure was trained in several rounds till satisfactory output was obtained with correlation value of R^2 = 0.97. The simulation procedure was tested in MATLAB and the program files were prepared to generate the goodness of fit parameters of the data points using correlation coefficients (R^2) and mean squared error (MSE) [17]. The mathematical expressions for the correlation coefficients and mean squared error (MSE) are shown in Eq. (5) and (6), respectively,

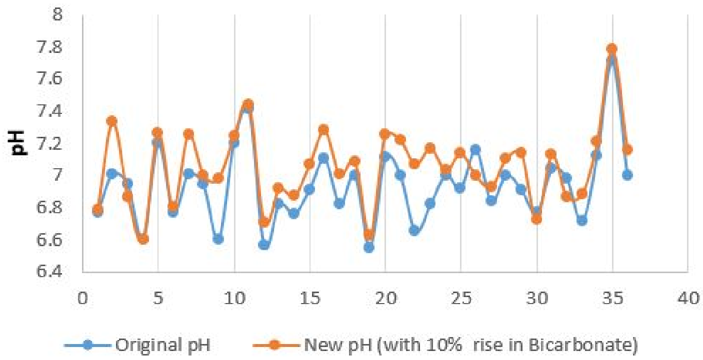
$$R^2 = 1 - \frac{\sum\left(Y_{\text{measured}} - Y_{\text{predicted}}\right)^2}{\sum\left(Y_{\text{measured}} - \frac{Y_{\text{predicted}}}{N}\right)^2} \tag{5}$$



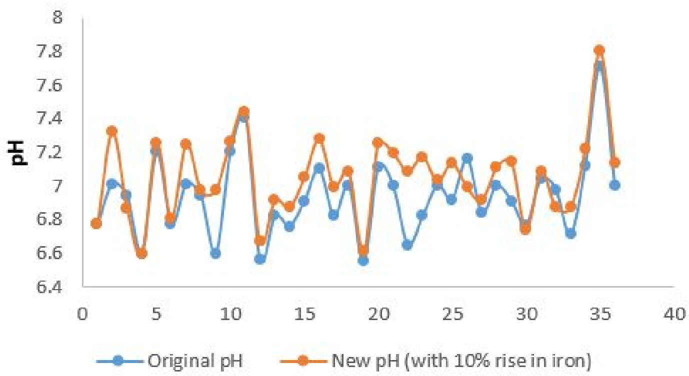
(a) Simulation of pH with 10% increase in nitrate



(b) Simulation of pH with 10% increase in chloride

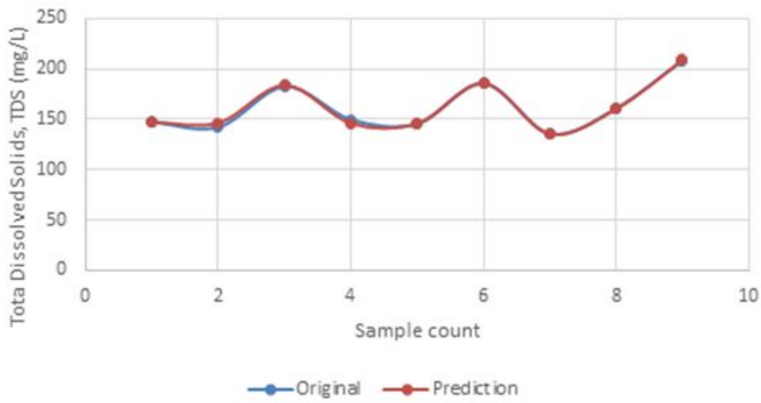


(c) Simulation of pH with 10% increase in bicarbonate

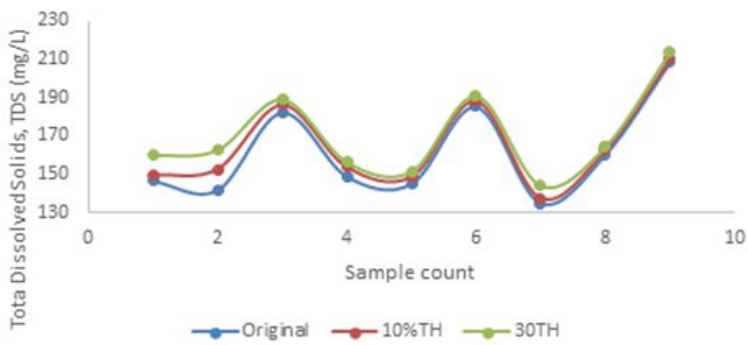


(d) Simulation of pH with 10% increase in iron

Figure 3: Simulation of pH with 10% increase in (a) nitrate, (b) chloride, (c) bicarbonate and (d) iron



(a) Original and predicted TDS



(b) Effect of total hardness on TDS

Figure 4: ANN prediction of TDS and effect on Total Hardness

$$\mathrm{MSE} = \frac{1}{\mathrm{N}} \sum_{i=1}^{N} \left(Y_{\text{measured}} - Y_{\text{predicted}} \right)^2 \qquad (6)$$

where N is the total number of data points predicted, Y_{measured} is the observe parameter and $Y_{\text{predicted}}$ is the calculated parameter (output).

The result of the simulation (Fig. 3) revealed that at the 10% increase in the values of chloride, nitrate, iron, and lead, the pH value of the water increased. In addition, the ANN provides a good prediction of TDS values for all water samples and the TDS increased with increase percentage of total hardness (Fig. 4).

4. CONCLUSION AND RECOMMENDATION

Generally, the groundwater in the study area is good for drinking except for some wells that are polluted considering the concentrations of nitrates, nitrites and lead, thus, a routine monitoring of the wells is recommended to track the source of the pollutants. The users of the affected wells should be properly informed and appropriate treatment methods should be advised. The simulation of the pH using Artificial Neural Network (ANN) provides a good match at 10% increment of chloride, nitrate and iron and the acidity of the water sources reduced with the corresponding increase in the parameters. The model gave a good prediction of TDS for all the water samples considered.

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