

ZIBELINE INTERNATIONAL  
PUBLISHINGISSN: 2521-0912 (Print)  
ISSN: 2521-0513 (Online)  
CODEN: JCOLBF

## RESEARCH ARTICLE

**INVESTIGATION OF HYDROGEOCHEMICAL PROCESSES IN GROUNDWATER RESOURCES LOCATED AROUND ABANDONED OKPARA COAL MINE, ENUGU SE. NIGERIA**

C. Ogwah\*, M. O. Eyankware

Department of Geology, Faculty of Science Ebonyi State University, Abakaliki, Nigeria.

\*Corresponding Author Email: [geomoses203@gmail.com](mailto:geomoses203@gmail.com)

This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

## ARTICLE DETAILS

## Article History:

Received 24 January 2020  
Accepted 26 February 2020  
Available online 23 March 2020

## ABSTRACT

A detail understanding of the hydrogeochemical characteristics and groundwater quality is indispensable for the sustainable utilization of the groundwater sources. This is in line with Sustainable development goal of United Nation. The following parameters were analyzed using APHA, 2012 standard: pH, Ec, total dissolved solid (TDS), total hardness (TH), magnesium ( $Mg^{2+}$ ), sulphate ( $SO_4^{2-}$ ), chloride ( $Cl^-$ ), bicarbonate ( $HCO_3^-$ ), carbonate ( $CO_3^{2-}$ ), nitrate ( $NO_3^-$ ), potassium ( $K^+$ ), sodium ( $Na^+$ ) and calcium ( $Ca^{2+}$ ). Findings revealed that pH value reveals that groundwater is acidic. Bivariate plots showed that groundwater quality is influenced by number of factors. Hydrogeochemical assessment of groundwater samples was based on the following model: End-member, Parson's and Diamond field plots. Results from these plots revealed that that silicate and carbonate weathering are that major factor that control groundwater quality, and that groundwater samples were of different water type namely; Ca-Mg-SO<sub>4</sub>, Ca-Mg-Cl, Na-SO<sub>4</sub> water type and high Ca + Mg & SO<sub>4</sub> + Cl respectively. It was observed that 99 % of groundwater within the study area fell within fresh water category and groundwater is influenced by various factors such as weathering.

## KEYWORDS

Groundwater, coal mine, Anambra Basin, weathering and Enugu.

## 1. INTRODUCTION

The history of coal industry in Nigeria was dated back to 1909, when coal was first discovered at the streams along Udi escarpment in Enugu State, Southeastern Nigeria (Buchanan, 1999). Enugu has been known for coal mining activities in time past, these mine were located at Udi, Onyeama, Okpara, Iva Valley and Ribadu respectively. Obiadi, et al., (2016) stated that the mining of coal was a major source of economic for people around the study area decades ago, the discovery of crude oil in south-south part of Nigeria has lead to low demand of coal. Increased demand for alternative energy sources and the country quest for improved power supply have led to attention be directed towards the exploitation of the crude oil as an alternative source of energy thereby neglecting coal deposit mineral within the study area. Coal mining, during that time gave rise to lots of mine waste which were dumped in landfills and surface dumps. Globally, mine waste are derived from active or abandoned mines, which is a serious problem due to its negative effects on the environment and water quality for domestic, industrial and irrigation use. As at that time, the sitting of these wastes dump sites were chosen for convenience and proximity to waste source rather than for environmental, geological, engineering consideration resulting in environmental degradation and potential groundwater contamination (Ezeigbo and Ezeanyim, 1993; Heikkinen, et al., 2009; Eyankware, et al., 2020; Moses and Ruth, 2015; Allen, et al., 1996). In addition, mine waste left near abandoned and active mines are major source of contamination to surface and groundwater quality. Water resource is threatened by mining activities across the world (Allen, et al., 1996; Choubey, 1991; Khan, et al., 2005; Singh, et al., 2008; Singh, 1998). Generally, the quality of groundwater is primarily influenced by the recharge pathways, anthropogenic activities and aquifer

rock mineral (Eyankware, et al., 2018). Obiadi, et al., (2016), is of the opinion that groundwater flows through its recharge pathways from recharge to discharge points, several other types of hydrogeochemical processes take place that alter physicochemical attribute of groundwater. Emphasis on the study is to evaluate the effect of abandoned coal mine over the years on geochemical quality of groundwater.

## 2. LOCATION, GEOLOGY AND HYDROGEOLOGY

The study area is located in Enugu State, Southeastern Nigeria. It lies between latitude 6°20'N-6°30'N and longitude 7°30'E -7°35' E (Figure 1). Kogbe stated that the coal deposit in Enugu area is mainly of sub-bituminous grade, black to brownish black in colour and is estimated at over 80 million tonnes (Kogbe, 1974). The outcrops of the coal were noticed along the road cut, Enugu escarpment, gullies and mine sites. The Enugu coal deposits as with most others coal deposits are associated with pyrite and marcasite which is stable below water table environment but is oxidized if exposed or the water table is lowered (Obiadi, et al., 2016). The mining processes remove the overburden materials and exposes mine spoils to oxidation. The Mamu Formation and the Nsukka Formation are the coal bearing formation of the Anambra Basin formally referred to as the lower coal measures and upper coal measures respectively. The coal seam varies with thickness from a few centimeters to about 2m. Obaje stated that the Mamu Formation (MF) marks the regressive phase of the Upper Campano-Maastrichtian transgressive cycle, the lithology of the Nsukka Formation is very similar to that of the MF and consists of an alternating succession of sandstone, dark shale and sandy shale, with few relatively thin coal seams at various positions in the lower horizons. Thin limestone occurs at the top of the sequence. Heikkinen, et al., (2009);

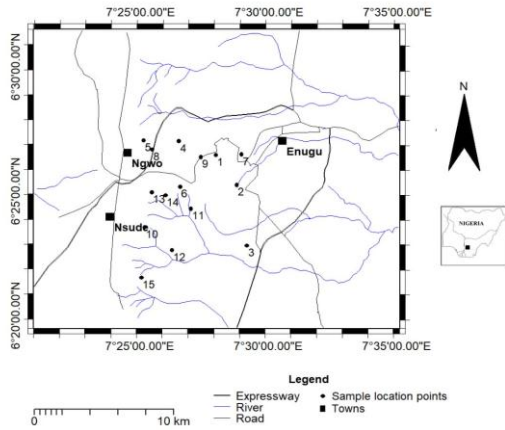
## Quick Response Code



## Access this article online

Website:  
[www.jcleanwas.com](http://www.jcleanwas.com)DOI:  
10.26480/jcleanwas.01.2020.12.16

Offodile, (2002) were of the opinion that the MF contributes nearly all the groundwater entering the Enugu coal mines. The source of recharge is by precipitation



**Figure 1:** Accessibility and Topographic Map of the Study Area.

### 3. MATERIALS AND METHODS

For the purpose of the study, fifteen (15) groundwater samples were collected and analyzed (Figure 1). Samples were collected in pre-cleaned, sterile polythene bottles of one capacity and were analyzed for major ions as per the standard methods of (APHA, 2012). The result of Result of physicochemical parameters are presented in Table 2. To check of accuracy of results ion balance equation was used to confirm the accuracy of sampled as shown in Eq. (1).

$$\text{Charger - Balance Error (CBE)} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100\% \quad \text{Eqn (1)}$$

Most of the sample has a % CBE within  $\pm 10\%$

### 4. RESULTS AND DISCUSSION

**Table 1:** Process/methods used to analyze physicochemical parameters.

S/No	Parameters	Analytical Method	Reference
1	pH	pH meter Hach sensION + PH1 portable pH meter and Hach sensION + 5050 T Portable Combination pH Electrode	(Gnanachandrasamy, et al., 2018)
2	Electrical Conductivity (Ec)	HACH Conductivity	(Gnanachandrasamy, et al., 2018)
3	Total dissolved solids (TDS)	TDS meters (model HQ14D53000000, USA).	(Gnanachandrasamy, et al., 2018)
4	Magnesium ( $Mg^{2+}$ )	EDTA titrimetric method	(Gnanachandrasamy, et al., 2018)
5	Calcium ( $Ca^{2+}$ )	Titrimetric method	(Gnanachandrasamy, et al., 2018)
6	Chloride ( $Cl^-$ )	Titrimetric method	(Gnanachandrasamy, et al., 2018)
7	Nitrate ( $NO_3^-$ )	Ion-selective electrode (Orion 4 star)	(Gnanachandrasamy, et al., 2018)
8	Sulphate ( $SO_4^{2-}$ )	Turbidimetric method using a UV-Vis spectrometer	(Gnanachandrasamy, et al., 2018)
9	Potassium ( $K^+$ )	Jenway clinical flame photometer (PFP7 model)	(Gnanachandrasamy, et al., 2018)
10	Sodium ( $Na^+$ )	Jenway clinical flame photometer (PFP7 model)	(Gnanachandrasamy, et al., 2018)
11	Bicarbonate ( $HCO_3^-$ )	Titrimetric method	(Gnanachandrasamy, et al., 2018)

**Table 2:** Results of Groundwater Samples.

Sample Code	pH	TDS (mg/L)	TH	Ec ( $\mu S/cm$ )	$CO_3^{2-}$ (meq/L)	$SO_4^{2-}$ (meq/L)	$Cl^-$ (meq/L)	$NO_3^-$ (meq/L)	$Ca^{2+}$ (meq/L)	$Mg^{2+}$ (meq/L)	$Na^+$ (meq/L)	$K^+$ (meq/L)	$HCO_3^-$ (meq/L)
OK/01	4.6	9.75	42.7	1038.14	0.18	0.29	0.10	0.02	3.05	0.14	0.27	0.06	0.16
OK/02	5.8	11.34	21.66	679.35	0.19	0.53	0.05	0.05	0.57	0.38	0.06	0.04	0.03
OK/03	4.9	56.45	81.00	76.04	0.26	0.77	0.07	0.09	0.05	0.76	0.11	0.03	0.18
OK/04	6.2	47.91	36.33	311.95	0.14	1.93	0.05	0.19	1.73	0.21	0.16	0.01	0.26
OK/05	6.8	16.71	116.00	96.84	0.22	2.26	0.03	0.26	0.50	0.66	0.05	0.04	0.14
OK/06	5.8	361.28	242.00	147.55	0.13	0.23	0.08	0.02	0.24	2.18	0.18	0.03	0.06
OK/07	4.7	14.61	139.00	396.84	0.04	0.15	0.05	0.06	0.42	0.97	0.12	0.44	0.11
OK/08	4.6	57.11	87.00	287.16	0.16	0.09	0.06	0.45	0.28	0.60	0.43	0.06	0.17
OK/09	5.2	181.23	97.00	47.00	0.16	0.29	0.05	0.76	0.17	0.80	0.71	0.01	0.12
OK/10	6.5	46.30	58	173.96	0.12	0.14	0.03	0.04	0.41	0.17	0.35	0.21	0.13
OK/11	6.2	62.06	98	208.64	0.05	0.21	0.05	0.02	0.35	0.63	0.21	0.01	0.16
OK/12	5.7	25.81	100	95.07	0.07	0.15	0.04	0.01	0.16	0.84	0.14	0.01	0.25
OK/13	4.2	57.05	168	274.87	0.01	0.46	0.06	0.07	0.25	1.43	0.22	0.05	0.46
OK/14	5.2	102.26	102	853.96	0.13	0.63	0.05	0.03	0.06	0.96	0.36	0.03	0.11
OK/15	4.5	27.12	133	551.14	0.24	0.16	0.01	0.02	0.03	1.30	0.15	0.02	0.15
<b>Min</b>	4.2	9.75	21.66	47	0.01	0.09	0.01	0.01	0.03	0.14	0.05	0.01	0.03
<b>Max</b>	6.8	361.28	242	1038.14	0.26	2.26	0.1	0.76	3.05	2.18	0.71	0.44	0.46
<b>Mean</b>	5.40	85.17	105.02	371.97	0.13	0.62	0.05	0.16	0.66	0.84	0.25	0.08	0.17

#### 4.1 Ph

pH refers to the degree of acidity or alkalinity of a solution or water. It is a crucial indicator that can be used for assessing water quality and degree of contamination in water bodies. pH is considered as an important factor that influences water quality. Findings from Ezeigbo and Ezeanyim, Ezeigbo and Ezeanyim revealed that low pH values in waters is associated with the Okpara coal mine (Ezeayim et al., 1993). The pH values within the study area varies from 4.2 to 6.8 are an indicative that the groundwater is acidic (Table 2). The low pH values showed evidence of oxidation of pyrite causing acid mine drainage (Cathles, 1982).

#### 4.2 Total Dissolved Solid (TDS)

TDS signifies the various types of minerals present in water in dissolved form. TDS compose of carbonates, bicarbonates, silica, calcium, magnesium, chlorides, sulfates, phosphates, sodium and potassium (Gnanachandrasamy, et al., 2015; Adimalla, et al., 2018). The value of TDS ranges from 9.5 to 361.28 mg/L (Table 3). The plot of TDS against TH revealed that groundwater fell within fresh water category (Figure 2).

**Table 3:** TDS classification of groundwater, modified after (Freeze and Cherry, 1979).

TDS (mg/L)	Classification	Number of samples
<1000	Fresh water	OK/02-15
1000-10000	Brackish	OK/01
10000-100000	Saline Water	
100000	Brine	

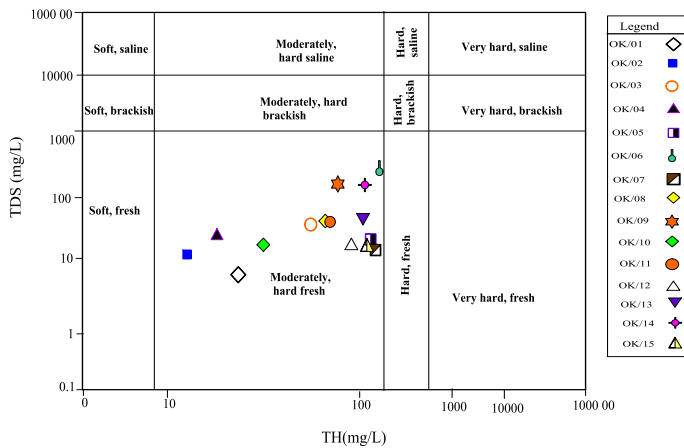
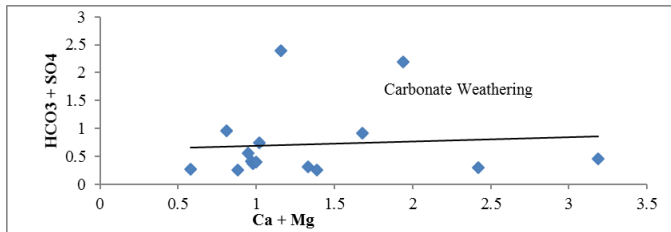


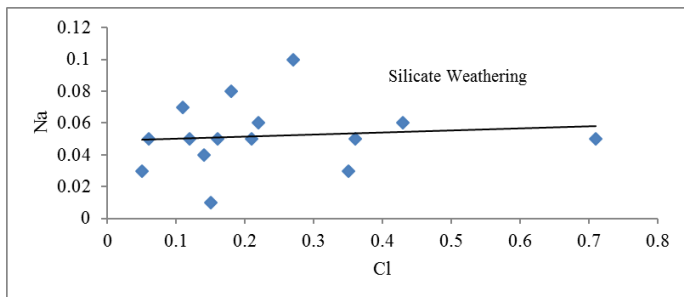
Figure 2: Plot of TDS vs. TH

4.3 Geochemical Mechanism of Groundwater

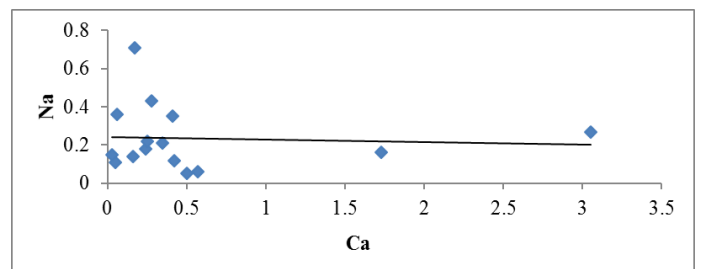
The plot of X-Y co-ordinate can be used to understand the geochemical variations in the ionic concentrations in the groundwater (Eyankware, et al., 2018). Results obtained from the chemical analyses were used to identify the geochemical processes and mechanisms in the groundwater system. The data obtained from analysed groundwater samples result were plotted in (HCO<sub>3</sub> + SO<sub>4</sub>) vs. (Ca + Mg) shows that majority of the samples fell below the equiline indicating that the silicate weathering is the considered to be dominant process that influence groundwater quality (Figure 3a). Whenever halite dissolution process is responsible for the Na<sup>+</sup> concentration in the groundwater, Na vs. Cl ratio should be approximately 1, whereas the Na vs. Cl ratio > 1 typically indicates that the sodium was released from silicate weathering (Figure 3b). Figure 3c showed that the ion exchange reactions, were Na is plotted against Ca in which Ca levels are ranges from 0.03 to 3.05 (meq/L), Na<sup>+</sup> levels are ranges from 0.05 to 0.71 (meq/L). The plot of Ec against Na/Cl reveals that the trend line is inclined with the increasing EC, indicating that the evaporation is not the dominant process (Figure 3d)



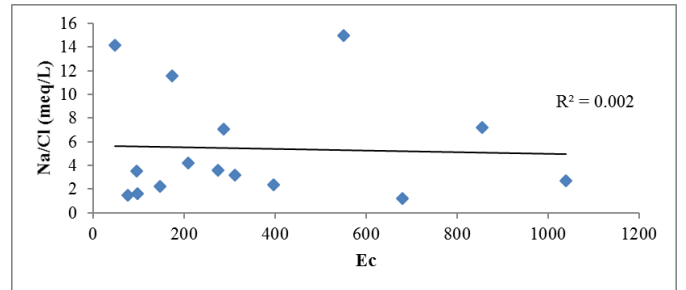
(a)



(b)



(c)



(d)

Figure 3: (a) Scatter diagram showing carbonate and silicate weathering Ca + Mg vs. HCO<sub>3</sub> + SO<sub>4</sub> (meq/L), (b) Showing scatter diagram of Na<sup>+</sup> vs. Cl<sup>-</sup> (meq/L), (c) Showing scatter diagram of Na<sup>+</sup> vs. Ca<sup>2+</sup> (meq/L), (d) Showing scatter diagram of Na/Cl vs. Ec plot.

Groundwater results sample was modeled after End-member plot (Gaillardet, et al., 1999). Figure 4 reveals that groundwater is influenced mostly by silicate weathering. From Parson plot groundwater within the study area are of different origin samples OK/01, 02, 03, 04, 05, 06, 07, 08, 09 and 11 are of Ca-Mg-SO<sub>4</sub> water type, samples OK/10 is of Ca-Mg-Cl water type. Samples OK/13, 15, 14, and 15 are of Na-SO<sub>4</sub> water type (Figure 5). The water classification of hydrogeochemical facies of Piper diagram was reconstructed by Lawrence and Balasubramanian, in the new reconstructed diamond field (Figure 6) (Lawrence and Balasubramania,, 1994). It classified water in the various zones on the basis of various reactions occurring in the groundwater aquifer system. The reconstructed diamond field shows that groundwater sample lies within High Ca+Mg+SO<sub>4</sub>+Cl hydrogeochemical facies as shown in Figure 6. This implies that, Ca and Mg, are the primary courses of hardness in water. Any water with high Ca + Mg is said to be hard.

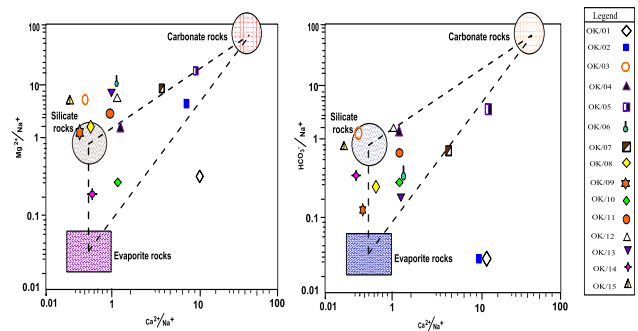


Figure 4: End-member plot for groundwater samples

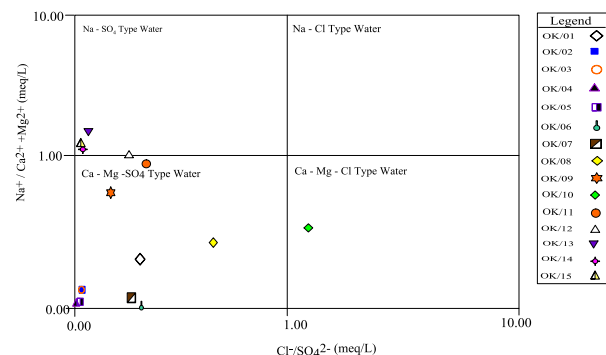
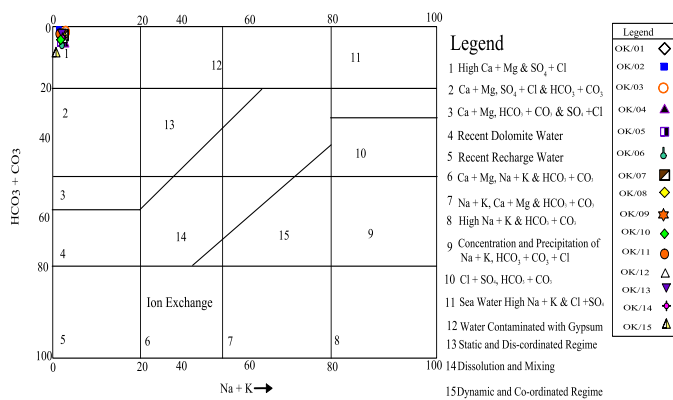


Figure 5: Showing Groundwater Origin on a Parson's Plot (Othman, 2005).



**Figure 6:** Classification of Hydrogeochemical Facies (Lawrence and Bal-Subramanian, 1994).

## 5. CONCLUSION

The prime objective of this study is to evaluate the influence of abandoned Okpara coal mine on groundwater quality using bivariate plot and hydrogeochemical approach. Result from findings revealed that pH value within the study area is said to be acidic, values obtained from TDS showed that groundwater fell within fresh water category. Bivariate plots revealed that groundwater is influence by various factors. Parson's and Diamond field plots showed that groundwater within the study area were characterized to be of different water type Ca-Mg-SO<sub>4</sub>, Ca-Mg-Cl and Na-SO<sub>4</sub> water type and groundwater samples fell within high Ca + Mg & SO<sub>4</sub> + Cl respectively. In conclusion groundwater within the study area is influenced by various factors.

## ACKNOWLEDGEMENT

The authors sincerely acknowledge the Editor-in-Chief of Bangladesh Journal of Scientific and Industrial Research. The anonymous reviewers are also appreciated for their constructive suggestions in bringing the manuscript to its present form. Last, but not the least, is Associate Professor. O. O. Omo-Irabor who prepared the maps on which the work is based.

## REFERENCES

- Adimalla, N., Vasa, S.K., Li, P., 2018. Evaluation of groundwater quality, Peddavagu in Central Telangana (PCT), South India: an insight of controlling factors of fluoride enrichment. *Model. Earth Syst. Environ.*, 4 (2), 841–852. <https://doi.org/10.1007/s40808-018-0443-z>.
- Allen, S.K., Allen, J.M., Lucas, S., 1996. Concentration of contaminants in surface water samples collected in west-central Indiana impacted by acid mine drainage. *Environ Geol.*, 27, 34–37.
- American Public Health Association (APHA). 2012. *Standard Methods for Examination of Water and Waste-Water*, twenty-second ed. American Public Health Association, Washington DC.
- Buchanan, 1999. *History of Coal Industry in Nigeria* Coal Science Education Journal, Pp. 2-7.
- Cathles, L.M., 1982. Acid Mine Drainage. *Journal of Earth and Mineral Sciences*, 51(4) pp 39.
- Choubey, V.D., 1991. Hydrological and environmental impact of coal mining, Jharia coalfield, India. *Environ Geol.*, 17, 185–194.
- Eyankware, M.O., Aleke, C.G., Selemo, A.O.J., Nnabo, P.N., 2020. Hydrogeochemical studies and suitability assessment of groundwater quality for irrigation at Warri and environs, Niger delta basin, Nigeria. *Groundwater for Sustainable Development*. doi: <https://doi.org/10.1016/j.gsd.2019.100293>
- Eyankware, M.O., Ogwah, C., Okeke, G., 2018. Geochemical Evaluation of Groundwater Origin using Source Rock Deduction and Hydrochemical Facies at Umuoghara Mining Area, Lower Benue Trough. SE. Nigeria.

*Intern Res. J. of Earth Sci.*, 6 (10), 1-8.

- Ezeigbo, H.I., Ezeanyim, B.N., 1993. Environmental pollution from coal mining activities in the Enugu Area, Anambra State, Nigeria. *Mine Water Environ.*, 12, 53–62.
- Freeze, R.A., Cherry, J.A., 1979. *Groundwater* Prentice Hall, Englewood Cliffs
- Gaillardet, J., Dupré, B., Louvat, P., Allègre, C.J., 1999. Global silicate weathering and CO<sub>2</sub> consumption rates deduced from the chemistry of large rivers. *Chem. Geol.*, 159, 3–30.
- Gnanachandrasamy, G., Ramkumar, T., Venkatramanan, S., Vasudevan, S., Chung, S.Y., Bagyaraj, M., 2015. Accessing groundwater quality in lower part of Nagapattinam district, Southern India: using hydrogeochemistry and GIS interpolation techniques. *Appl Water Sci.* DOI 10.1007/s13201-014-0172-z.
- Gupta, D.C., 1999. Environmental aspects of selected trace elements associated with coal and natural waters of Pench valley coalfield of India and their impact on human health. *Inter. J. Coal Geol.*, 40, 133–149.
- Heikkinen, P., Raisanen, M.L., Johnson, R.H., 2009. Geochemical Characterization of Seepage and Drainage Water Quality from Two Sulphide Mine Tailings Impoundments: Acid Mine Drainage versus Neutral Mine Drainage. *Mine Water Environ.*, 28, 30–49. DOI 10.1007/s10230-008-0056-2.
- Khan, R., Israili, S.H., Ahmad, H., Mohan, A., 2005. Heavy metal pollution assessment in surface water bodies and its suitability for irrigation around the Nayevli lignite mines and associated industrial complex, Tamil Nadu, India. *Mine Water Environ.*, 24, 155–161.
- Kogbe, C.A., 1974. *The Cretaceous and Palaeogene Sediments of Southern Nigeria*. In: Kogbe CA (ed) *Geology of Nigeria*. Elizerbertan Publication, Lagos, Pp 538.
- Lawrence, J.F., Balasubramanian, A., 1994. Groundwater condition and disposition of salt-fresh water interaction in the Rameswaram island, Tamilnadu; Regional workshop on environment aspect of groundwater development, October 17–19, Kurukshetra, India
- Moses, O.E., Ruth, O.E., 2015. Environmental Degradation on Land in Enyigba with Reference to Artisan Lead-Zinc Miner in South Eastern Nigeria. *Journal of Multidisciplinary Scientific Research*, 3 (3), 32-34.
- Narsimha, A., Ajay, K., Taloor, 2020. Hydrogeochemical investigation of groundwater quality in the hard rock terrain of South India using Geographic Information System (GIS) and groundwater quality index (GWQI) techniques. *Groundwater for Sustainable Development*. <https://doi.org/10.1016/j.gsd.2019.100288>
- Obaje, N.G., 2009. *Geology and mineral resources of Nigeria*. Springer, New York 222.
- Obiadi, I.I., Obiadi, C.M., Akudinobi, B.E.B., Maduwesi, U.V., Ezim, E.O., 2016. Effects of coal mining on the water resources in the communities hosting the Iva Valley and Okpara Coal Mines in Enugu State, Southeast Nigeria. *Sustain. Water Resour. Manag.*, 2, 207–216. DOI 10.1007/s40899-016-0061-8
- Offodile, M.E., 2002. *Groundwater Study and Development in Nigeria*, Second edition, Mecon Geology and Engineering Services Ltd, Jos, Nigeria, 364– 393.
- Singh, A.K., Mondal, G.C., Kumar, S., Singh, T.B., Tewary, B.K., Sinha, A., 2008. Major ion chemistry, weathering processes and water quality assessment in upper catchment of Damodar River basin, India. *Environ Geol.*, 54,745–758.
- Singh, G., 1998. Impact of coal mining on mine water quality. *Int J. Mine Water.*, 7, 45–59