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Quality Evaluation And Health Risk Assessment Of Groundwater And Ambient Air In Selected Quarry Sites In Southeastern Nigeria

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Abstract –
This study evaluated the effects of stone cutting activities at Ngwama, Imama and Ngodo quarry sites in Southeastern Nigeria on drinking water and air quality indices, and the probable human health risks associated with consumption of water from these quarry sites. Physicochemical parameters, heavy metal levels and microbial indices in drinking water were determined using standard analytical methods. Results for physicochemical indices indicated non-compliance with WHO and NSDWQ permissible limits for appearance, taste, total coliform count and turbidity. Bacteriological results indicated total coliform count of 0.94 ± 0.05, 1.12 ± 0.12 and 0.82 ± 0.05 Cfu/100ml for Ngwama, Imama and Ngodo quarries respectively. Alkalinity, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and Conductivity, Calcium and Magnesium Hardness, Bicarbonate, Asbestos, SO_4 and Nitrates in drinking water were within permissible limits. Iron (Fe) in drinking water ranged from 1.04 ± 0.05 mg/kg to 2.46 ± 0.26 mg/kg, indicating exceedances over WHO and NSDWQ permissible limits of 0.3 mg/kg for Fe in drinking water. Ambient air quality indices and noise level were with permissible limits. Carcinogenic Risk (CR) assessment values in the sampled drinking water samples was significantly ($p<0.05$) high Cu in both adult and children populations, indicating high potential for carcinogenic risk while values for Fe, Mn, F, Na and As were within regulatory threshold. Our findings demonstrate that activities at the rock quarries have adverse impact on the drinking water and further confirm that there are significant health risks associated with groundwater within the quarry sites.

Keywords: *Health Risk Assessment; Groundwater; Quarry; Air quality; Heavy metals*

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I. Introduction

Meeting the demand for infrastructure development for a country, especially roads and other construction ventures, require harnessing potential sources of raw materials such as aggregates, gravel, sand, and limestone. The ever increasing demand for these rock materials has led to an escalation in quarrying activities and has attracted many companies within the building and construction sector to invest in stone quarrying [1].

Irrespective of improving people's livelihoods, mineral extraction and rock quarrying activities often impart long-term environment and social-economic footprints in areas in which it is carried out [3, 4]. Various sorts of environmental harm and risks are associated with stone cutting activities [5]. A previous report by Garba [6] indicates that people living close to quarries are affected by the activities that go on in that area. Workers and their family who are residing close to these units are more vulnerable to silica exposure. The children, women and elderly are all breathing these toxins regularly [6].

The environmental impact of mining quarrying activities is very complex and it not only destroys the existing vegetation but also affects the surface and ground water quality [7]. Ground water quality can be affected by blasting of rocks which has been ascertained as the one major problem 8]. Aquatic communities can be affected through release of quarry effluents, silts and other poisonous substances into the water bodies like, streams, rivers and ponds [9]. Quarrying in conjunction with rock blasting can close the flow of ground water in the karst area, or lead in the change of flow rate of ground water direction and new route openings [10]. Hire Khan et al.[11] reported that the ground water in mining area have low pH due to pyretic rocks at the bottom.

Dust from quarries is a major source of air pollution, although the severity will depend on factors such as the local climate, the concentration of dust particles in the surrounding air, the size of the dust particles, and their chemical constituents because limestone quarries produce highly alkaline (active) dust while granite quarries produce acidic dust [12]. Dust is caused by explosions, material handling, wind blows, soil erosion, and truck movement [13]. The wastes from industry like gases, dust, solutions, and variety of minerals such as tailing containing trace and toxic elements pollute water environment [7].

The number of quarry industries in Southeastern Nigeria is on the rise. Quarry activities at this location have had a devastating impact on the environment, with the explosive explosion of rocks causing air pollution, water pollution, biodiversity damage, and man-made environmental degradation that negatively impacts the environment of a specific area through unfinished or abandoned pits that leave a large open space. This does not only looks like an eyesore but also endangers livestock, wildlife, and humans [14]. Air pollution in the form of particles (dust) can also have significant effects on surrounding plants [15].

This study intends to examine the environmental impact of quarrying on groundwater and air quality indices so as to detect drinking water and air pollutants at the quarry sites. Also, the study evaluates the probable human health risks associated with consumption of water from these quarry sites.

II. Materials And Methods

Study Area

This study focused on Ngwama, Imama and Ngodo quarry sites in Eastern Nigeria. The study area (shown in Fig. 1) is located in Ebonyi State, Southeastern Nigeria. Ebonyi State lies approximately within latitudes 5° 40' and 6° 45' North of the Equator and longitudes 7°30' and 8°30'East of the Greenwich meridian. The area is characterized primarily by two regimes which are the rainy and the dry seasons. Ebonyi State is bordered by Benue State to the north, Enugu State to the west. Cross River State to the east, and Abia State to the south. Ebonyi State has a population of approximately 3.52 million, with a growth rate of 2.8% since 2022 [11]. The quarrying sites are located at Ngwama in Izzi Local Government Area (LGA), Imama in Afikpo North Local Government Area (LGA) and Ngodo in Afikpo Local Government Area (LGA) of Ebonyi State, Nigeria. The sites have been in operation since at least 1995, when the communities started stone mining for building works and paving [16]. Plates 1 and 2 show harvested stones after blasting and stones crushed into sizes.

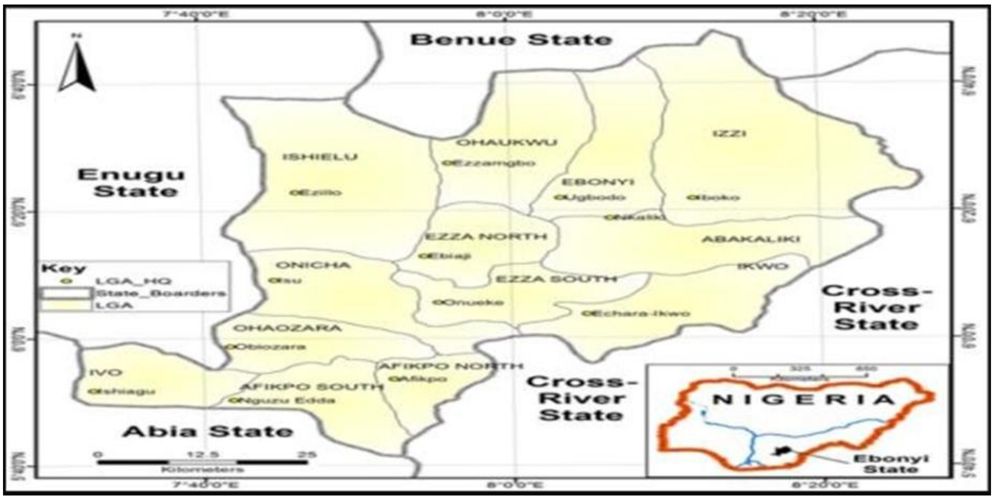

Figure 1. The study area: Ebonyi State, South-Eastern Nigeria

Methods

Water Sample Collection:

Borehole water samples were collected from five different sites at each of the three selected Quarry sites. The samples were collected in 5-litre plastic containers, which were thoroughly washed twice with the water to be analyzed.

Table 1: Sample Grouping

	Ngwama Quarry	Imama Quarry	Ngodo Quarry
Groundwater Sample	NGWgw	IMAgw	NGOgw
Ambient air	NGWaa	IMAaa	NGOaa

Groundwater Sample Analysis:

The color of water samples was determined using visual comparison method. Total Suspended Solids was determined according to the APHA 2540-D method [17] while Total Dissolved Solid was determined using APHA 2540-C method [18]. Conductivity was determined using electronic conductivity measurement set [19]. Analysis for microbial parameters in the water samples were done according to APHA [20] standard methods. Turbidity was determined photometrically using a turbidimeter. Temperature was determined in situ by dipping the thermometer of 110°C calibration range into the water and the reading is taken after 5 minutes' interval. Water pH was determined in situ; the indicator electrode of a pH meter immersed, allowed for few minutes to let the reading settle and the final reading was recorded. Determination of alkalinity of water sample is generally carried out experimentally by titration method using a proper indicator [21]. Calcium and Magnesium hardness, and Bicarbonate were determined by EDTA titrimetric method described by AOAC [22]. Asbestos fiber concentration in water samples was measured using the method described by USEPA [23]. The method of APHA [24] was used for the determination of sulphate in the water samples. Nitrate in water was determined using standard spectrometric techniques. The level of metals (Iron, Manganese, Flouride, Sodium, Arsenic and Copper) in water was determined using Atomic Absorption Spectrophotometer method (UNICAM) [25].

Air Quality Determination

Air was trapped at five different locations within each quarry site using series of hand-held air quality monitoring equipment and air pollutants measured immediately. An industrial scientific corporation IBRID MX6 Multi-Gas Monitor was used for the detection of CO, SO_2, NH_3, NO_2, CO_2, H_2S, CH_4 and VOCs. A Krestel hand held weather trucker was used to determine the wind speed, temperature and relative humidity. PM10 AND PM2.5 emissions were measured using Method 201A [26]. An Extech model 407736 sound level meter was used to measure noise level of the locations.

III. Results And Discussion

Aesthetic aspects of groundwater quality

Water samples from Ngwama, Imama and Ngodo quarry sites showed observable colours and objectionable taste at the time of sample collection. As suggested by Okoro et al. [27], colour in drinking water may be due to the presence of coloured organic matter, e.g. humic substances, metals such as iron and manganese, or highly coloured industrial wastes. The World Health Organization (WHO) [28] recommends that drinking water should be colourless. The observable water colouration and objectionable taste and odour observed in the Quarry water samples is indicative of water pollution caused by continuous rock quarrying activities [27].

Table 2. Physicochemical and Microbial Parameters in Groundwater Samples

Parameters	NGW_{gw}	IMA_{gw}	NGO_{gw}	WHO [29]; NSDWQ [30]
Appearance	Slightly coloured	Slightly coloured	Coloured	Clear
Taste	Objectionable	Objectionable	Objectionable	Unobjectionable
TDS (mg/l)	0.2033 ± 0.0058^{ab}	0.1300 ± 0.0200^{ab}	0.7333 ± 0.1537^{c}	500
TSS (mg/l)	14.8800 ± 0.5147^{a}	11.0500 ± 0.7378^{b}	21.9567 ± 1.4420^{c}	25
Conductivity (μs/cm)	12.4767 ± 0.6422^{a}	25.1733 ± 1.2390^{b}	31.5833 ± 1.2513^{c}	1200
Total Coliform (CFU/100ml)	0.9433 ± 0.0551^{ac}	1.1200 ± 0.1253^{b}	0.8200 ± 0.0529^{ac}	0
Turbidity (NTU)	7.3600 ± 0.3378^{a}	17.0100 ± 1.0413^{b}	28.0967 ± 0.8690^{c}	5
Temp (ºC)	27.8233 ± 0.0058^{a}	30.7433 ± 0.0200^{b}	25.9667 ± 0.1537^{c}	25

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at P ≤ 0.05 across the groups.

Table 3. Chemical Parameters in Groundwater Samples

Parameters	NGW_{gw}	IMA_{gw}	NGO_{gw}	WHO [29]; NSDWQ [30]
pH	6.8167 ± 0.1877^{ac}	7.6167 ± 0.1960^{b}	$7.1667 \pm 0.1756a^{c}$	6.5-8.5
Alkalinity (mg/l)	38.0367 ± 0.3465^{a}	42.0400 ± 0.7848^{b}	68.8800 ± 1.0309^{c}	NS
Calcium Hardness (mg/l)	10.8333 ± 0.7716^{a}	28.0000 ± 0.8200^{b}	14.1567 ± 0.2836^{c}	600
Magnesium Hardness (mg/l)	0.7067 ± 0.0651^{ab}	0.7133 ± 0.0611^{ab}	1.0033 ± 0.0252^{c}	20
Bicarbonate (mg/l)	33.0100 ± 0.0173^{a}	25.5600 ± 1.1945^{b}	39.1133 ± 0.3951^{c}	N.S
Asbestos(mg/l)	0.1367 ± 0.0153^{a}	0.0433 ± 0.0058^{b}	0.2400 ± 0.0361^{c}	N.S
SO4 (mg/l)	0.5333 ± 0.1557^{abc}	0.5833 ± 0.1595^{abc}	0.3400 ± 0.0964^{abc}	500
Nitrates (mg/l)	1.0400 ± 0.0819^{a}	0.0000 ± 0.0000^{b}	0.8200 ± 0.0700^{c}	50

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at P ≤ 0.05 across the groups.

Table 4. Heavy Metals Concentration in Groundwater Samples

Metals	NGW_{gw}	IMA_{gw}	NGO_{gw}	WHO [29]; NSDWQ [30]
Fe (mg/kg)	1.7767 ± 0.1168^{abc}	1.0467 ± 0.0569^{abc}	2.4633 ± 0.2641^{abc}	0.3
Mn (mg/kg)	0.1300 ± 0.0436^{ab}	0.1200 ± 0.0100^{ab}	0.2433 ± 0.0586^{c}	0.4
F (mg/kg)	0.0700 ± 0.0000^{a}	1.1033 ± 0.0833^{b}	0.4167 ± 0.0306^{c}	1.5
Na (mg/kg)	10.5900 ± 0.5525^{a}	7.1433 ± 0.9019^{b}	16.8833 ± 0.7650^{c}	<20
As (mg/kg)	BDL	BDL	BDL	0.01
Cu (mg/kg)	0.0333 ± 0.0058^{a}	0.0500 ± 0.0000^{b}	0.0833 ± 0.0058^{c}	2

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at $P \leq 0.05$ across the groups.

Table 5. Ambient Air Quality around Quarry Locations

Parameters	NGW_{aa}	IMA_{aa}	NGO_{aa}	WHO [29]
PM 2.5 (μg/m3)	0.0367 ± 0.0058^{a}	0.0733 ± 0.0116^{bc}	0.0767 ± 0.0116^{bc}	5
PM 10 (μg/m3)	0.4900 ± 0.0529^{a}	0.7567 ± 0.0603^{b}	0.2567 ± 0.0116^{c}	15
CO_2 (ppm)	333.0967 ± 2.9162^{a}	420.2400 ± 1.8087^{b}	499.7367 ± 1.6211^{c}	N.S
NO_2 (μg/m3)	0.1933 ± 0.0116^{a}	0.1533 ± 0.0289^{b}	0.0500 ± 0.0000^{c}	10
CH_4 (ppm)	BDL	BDL	BDL	N.S
VOC	1.0500 ± 0.0557^{ac}	2.2400 ± 0.1819^{b}	1.2100 ± 0.1353^{ac}	N.S
SO_2 (μg/m3)	0.0047 ± 0.0006^{a}	0.0017 ± 0.0006^{bc}	0.0020 ± 0.0010^{bc}	40
CO (mg/m3)	BDL	BDL	BDL	4
NH_3 (ppm)	0.1000 ± 0.0000^{ab}	0.1133 ± 0.0153^{ab}	0.1800 ± 0.0173^{c}	0.20
H_2S (ppm)	0.0020 ± 0.0000^{a}	0.0057 ± 0.0006^{b}	0.0077 ± 0.0015^{c}	0.008
Temp (ºC)	36.6500 ± 0.5726^{a}	31.3633 ± 0.9029^{bc}	30.7400 ± 0.5484^{bc}	N.S
Noise (db)	81.8633 ± 2.2805^{abc}	78.9133 ± 6.7521^{abc}	79.7067 ± 1.6269^{abc}	85

Values are presented as mean ± SD of triplicate determination (N=3). Mean values with same superscript letters are not statistically significant at $P \leq 0.05$ across the groups.

Table 6. Estimated Daily Intake (EDI) (mg/kg/person) of Heavy Metals in Groundwater Samples

	Adult			**Children**		
Metals	NGW_{gw}	IMA_{gw}	NGO_{gw}	NGW_{gw}	IMA_{gw}	NGO_{gw}
Fe	5.0763E-02	2.9906E-02	7.0380E-02	7.4029E-02	4.3613E-02	1.0264E-01
Mn	3.7143E-03	3.4286E-03	6.9514E-03	5.4167E-03	5.0000E-03	1.0138E-02
F	2.0000E-03	3.1523E-02	1.1906E-02	2.9167E-03	4.5971E-02	1.7363E-02
Na	3.0257E-01	2.0409E-01	4.8238E-01	4.4125E-01	2.9764E-01	7.0347E-01
As	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cu	9.5143E-04	1.4286E-03	2.3800E-03	1.3875E-03	2.0833E-03	3.4708E-03

Table 7. Targeted Hazard Quotient (THQ) and Targeted Hazard Index (THI) ($Person^{-1}$) of Metals in Groundwater Samples

	Adult			**Children**		
Metals	NGW_{gw}	IMA_{gw}	NGO_{gw}	NGW_{gw}	IMA_{gw}	NGO_{gw}
Fe	7.2518E-02	4.2722E-02	1.0054E-01	1.0576E-01	6.2304E-02	1.4663E-01
Mn	2.6531E-02	2.4490E-02	4.9653E-02	3.8690E-02	3.5714E-02	7.2411E-02
F	3.3333E-02	5.2538E-01	1.9843E-01	4.8611E-02	7.6618E-01	2.8938E-01
Na	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
As	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cu	2.3786E-02	3.5714E-02	5.9500E-02	3.4688E-02	5.2083E-02	8.6771E-02
THI	1.5617E-01	6.2831E-01	4.0812E-01	2.2775E-01	9.1628E-01	5.9518E-01

Table 8. Carcinogenic Risk (CR) of metals in Groundwater Samples

	Adult			**Children**		
Metals	NGW_{gw}	IMA_{gw}	NGO_{gw}	NGW_{gw}	IMA_{gw}	NGO_{gw}
Fe	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Mn	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
F	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Na	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
As	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
Cu	7.6114E-04	1.1429E-03	1.9040E-03	1.1100E-03	1.6667E-03	2.7767E-03
TLCR	7.6114E-04	1.1429E-03	1.9040E-03	1.1100E-03	1.6667E-03	2.7767E-03

Physicochemical and microbial aspects of groundwater quality

Temperature of groundwater samples investigated was found to be in the range of 25.96°C and 30.74° C. Turbidity of all the samples exceeded the range of permissible limits, ranging from 7.36 ± 0.33 to 28.09 ± 0.86 NTU. This finding is at variance with the research work by ParameSha naik et al.[7] on ground water quality evaluation in stone quarry area where they reported turbidity in all the analysed samples to be within the range of permissible limits.Turbidity in water is caused by suspended matter such as clay, silt, and finely divided organic and inorganic matter [31].

Values for total dissolved solids (TDS), total suspended solids (TSS) and electrical conductivity (EC) in groundwater samples were below WHO/NSDWQ regulatory standards for safe drinking water. Electrical conductivity values ranged between 12.4767 ± 0.64 and 31.5833 ± 1.25 µs/cm, within the permissible limits of 1200µs/cm. Higher values suggest the presence of high amount of dissolved inorganic substance in ionized form, probably due to the input of large amounts of salts and silts.

Results presented in Table 2 show total coliform count of 0.94 ± 0.05, 1.12 ± 0.12 and 0.82 ± 0.05 CFU/100ml for Ngwama, Imama and Ngodo quarry sites respectively. Total coliform count exceeded WHO/NSDWQ permissible limits of 0.00Cfu/100ml for safe drinking water. WHO [29] suggests that total coliform bacteria should be absent in drinking water; their presence in water indicates that water is not treated properly and is not suitable for drinking purpose. This finding corroborates previous reports of heavy presence of total coliform bacteria in quarry water [27, 32].

Other chemical aspects of groundwater quality

The results of the chemical parameters analyzed are given in Table 3 and are compared with water quality standards of WHO [29] and NSDWQ [30].

The pH of the water samples ranged between 6.81 - 7.61, which are pH values within the permissible limits. None of the quarry showed a high concentration of Total dissolved solids in groundwater samples. Nordestron [33] reported that high TDS content limits or determines the use of ground water for any purpose. Water with high dissolved solids is generally of inferior palatability and may induce an unfavorable physiological reaction in transient consumers [7]. Calcium Hardness, Magnesium Hardness, Bicarbonate and Asbestos showed values within permissible limits (Table 3). The heavy presence of carbonates and bicarbonates of calcium and magnesium, sulphates, chlorides, nitrates, influence the ground water to become hard. Alkalinity of ground water is due to the presences of carbonates, bicarbonates and hydroxides. Alkalinity values in this study were within standard limits.

Sulphates ions originate in natural water due to oxidation of sulphite ores or gypsum and other sulphur bearing ores. However ingestion of water containing high concentration of sulphate can have laxative effects, which is enhanced when sulphate is consumed in combination with magnesium [7]. Sulphate values in all the samples analyzed were within recommended limits.

Nitrates occur in ground water mainly due to leaching from soil organic matter, fertilizers applied to soil, refuse dumps and releases from industrial discharges. Knobeloch et al. [34] noted that in excessive amounts, nitrate contributes to the illness of infant methemoglobinemia or blue baby syndrome. The level of nitrates in the analyzed ground water samples were observed to fall within the permissible limits of 50mg/l.

Metals in groundwater samples

Generally, the mean concentration of the heavy metals in groundwater samples collected from Ngwama, Imama and Ngodo quarry sites was in the order Na>Fe>Mn>F>Cu>As. Results obtained for Fe were found to exceed permissible values of 0.3 ppm. High concentration of Fe in groundwater samples could be an indication of higher dissolution of minerals due to quarrying activities or variations in geo-chemical parameters [35]. Bothwell et al. [36] reported that medical conditions such as haemorrhagic necrosis and sloughing of areas of mucosa in the stomach with extension into the submucosa could be associated with chronic iron overload [32]. The concentration of Na, Mn, F, Cu and As in the analysed groundwater samples were within WHO [29] and NSDWQ [30] recommended values.

Ambient Air Quality

Potential anthropogenic sources of SPM in the study area include fumes from processing/crushing plant, blasting activities, haulage of crushed rocks, welding activities, exhaust fumes from many sources e.g. heavy duty vehicles, power generating plant etc [27]. According to Table 5, the concentration levels of particulate matter (PM10) in the various locations studied are lowest at 0.49 ± 0.05, 0.75 ± 0.06 and 0.25 ± 0.01 µg/m^3 for Ngwama, Imama and Ngodo quarry sites. Methane (CH4) and Carbon Monoxide (CO) concentrations in ambient air were below detection limits. Prolonged and excessive inhalation of fine particulates may cause cancer and aggravate morbidity and mortality from respiratory dysfunctions [27]. Long term exposure to NO2 concentrations above 563ppm may cause pulmonary disease and increase susceptibility to bacterial infection in man [37]. Interestingly, the ambient air quality parameters (PM 2.5, PM 10, CO_2, NO_2, CH_4, VOC SO_2 CO and NH_3) for the three quarry sites under study where all within WHO [29] permissible limits.

Within the study area, noise is generated from rock blasting site, crush rock processing plants, haulage trucks, diesel power generating plant, heavy duty trucks, welding machines, heavy traffic on the highway traffic hooting and human activities in the neighborhood. Although Ngwama quarry site recorded noise level as much as 81.86 ± 2.28 db, the three quarry sites under study were observed to have noise levels consistent with permissible exposure limits (85db).

Carcinogenic Risk Assessment

Result showing the lifetime carcinogenic risk assessment for heavy metals in groundwater, for children and adults is presented in Table 8. No trace of the potential carcinogenic risk was recorded for Na, Mn, F, Fe and As in both adult and children populations. the lifetime carcinogenic risk assessment of these metals showed mean values that fell within the regulatory threshold of 10E-6 – 10E-4. However, Carcinogenic Risk (CR) assessment of Cu showed values that were significantly ($p<0.05$) high in both adult and children populations. It follows that there is high carcinogenic risk due to the presence of Cu in groundwater samples from the three quarry sites.

IV. Conclusion

Our findings reveal that activities at the rock quarry sites have adverse impacts, particularly on groundwater. Ambient air quality does not pose significant health risk to residents within the quarry environs. However, high carcinogenic risk for Cu in groundwater exists in both adult and children populations.

Compliance With Ethical Standards

Disclosure of Conflict of interest

Authors have declared that no competing interests exist.

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