

IMPACTS OF LIMESTONE MINING AND PROCESSING ON WATER QUALITY IN ASHAKA AREA, NORTHEASTERN NIGERIA

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Abstract

The impacts of limestone mining and processing on water resources in Ashaka area of North-Eastern Nigeria was investigated in this study. Ashaka is located about 140 km north of Gombe town, in between hills and Gongila valley, covering an area of about 25km². Samples were collected from hand-dug wells, boreholes, surface water, mine ponds and waste water and taken to the laboratory for relevant analysis. The hydrochemical facies analysis revealed three water types in the area in the order of: Ca-Mg-SO₄, Ca-Mg-HCO₃ and Ca-Mg-SO₄-HCO₃ an indication that the water type in the area is closely related to the local geology of the area. The high concentration of carbonates and bicarbonates in the water are derived from bedrock dissolution and weathering while fluoride and heavy metal enrichment in the water may be due to mining and processing of limestone in the area and application of fluoride-rich fertilizer. The degree of accumulation of the metals are in the order of Mn > F > Cd > Fe > Cu > As > Pb > Ni > Cr. This implies that Mn has the highest water pollution index while Cr has the least water pollution index. Government all levels should enforce the treatment of industrial effluent before discharging them into the rivers Alternative source of drinking water should be provided to the host communities where their surface and hand-dug wells have been polluted by effluent from the cement factory. Periodic assessment of the various water sources should be undertaken in the area in order to adequately monitor the pollution status of the water resources in the area.

Keyword: Impact Assessment, Water Quality, Limestone Mining and Processing, Ashaka Area, Northeastern Nigeria

1.0. Introduction

There has been an increasing rise of environmental pollution globally as a result of man's activities such as mining, industrial effluent and sewage disposals into the ecosystem. Heavy metals are widespread pollutant of great environmental concern as they are non-degradable, toxic and persistent with serious ecological ramifications on local geology and ecology. In Nigeria, varying degrees of soil, water and air pollution occur in the course of mineral prospection, exploration and exploitation depending on the stage and scale of activities attained. Limestone is a sedimentary rock chiefly composed of calcium carbonate. It is formed by the compaction of corals, plants or animal remains through the action of rivers, sea, wind, and glaciers (Okosun and Liebau, 1999). It is formed by direct crystallization of carbonates with some impurities such as clay, sandstone, and shale (Venugopal *et al.*, 2009). It is the most widely used non-metallic raw material in Nigeria (Tijani *et al.*, 2004). The largest use of

limestone is in the manufacture of cement used in construction industry. Limestone deposit is also primary raw materials for some manufacturing industries such as sugar, fertilizer, and ceramics, iron, glass, chemicals, fillers and extenders.

Though limestone mining has a lot of economic benefits, the associated environmental and health effects in terms of land degradation, air pollution, surface and groundwater pollution can be devastating (Aigbedion and Iyayi, 2007). The environmental effect of mining dependent on the extraction techniques as the impact of open-cast mining on the environment may differ from underground mining. According to Amadi, (2009) mining is an integral part of development of civilization and early mining operations have left a historical legacy of negative environmental impacts that affect our perception on mining and this is occasioned by the crude mining equipment. The exploration, exploitation and processing of limestone have adversely affected the environment (Singh et al., 2008; Sundaray, 2009). Limestone deposits are greatly influence by geological factors such as deposit size, host-rock lithology, wall-rock alteration, nature of ore, trace element geochemistry, ore and gangue mineralogy and zonation, topography, physiography and climate, mining and milling method employed (Sekabira et al., 2010; Amadi et al., 2012). According to Weber-Fahr (2002), surface mining though less dangerous than underground mining, has a greater impact on surface landscape. Opencast mining requires the removal of massive amount of top soil in order to gain access to the mineral, which can cause erosion, loss of habitat, and dust pollution leading to soil, surface and groundwater contamination. Vast agricultural lands are destroyed through opencast mining thereby affecting food production and source of income for the people (Weber-Farh, 2002, Amadi, 2011). According to (Amadi et al., 2013) abandoned mine resulting from mine closure causes water pollution and damage to the environment such as dust, noise, leaching and subsidence. Improper management of mine waste causes increased concentration of toxic substances in soil, water and aesthetic problems. Pollution caused by quarrying and blasting in opencast mine increases not only the dust in the air but also promotes the spread of toxic chemicals and oxides (Akabzaa, 2000, World Bank, 2001; Sekabira et al., 2010; Singh et al., 2008; Sundaray, 2009).

Description of the study area

The study area is Ashaka, in Funakaye Local Government Area of Gombe State. It covers an area of about 25km² and about 140km north of Gombe town. It lies between longitude 11°25'E to 11°32'E of the Greenwich Meridian and latitude 10°50'N to 11°00'N of the Equator. The area is accessible through Gombe-Bajoga-Ashaka Cement Factory and Gombe-Maiduguri railway.

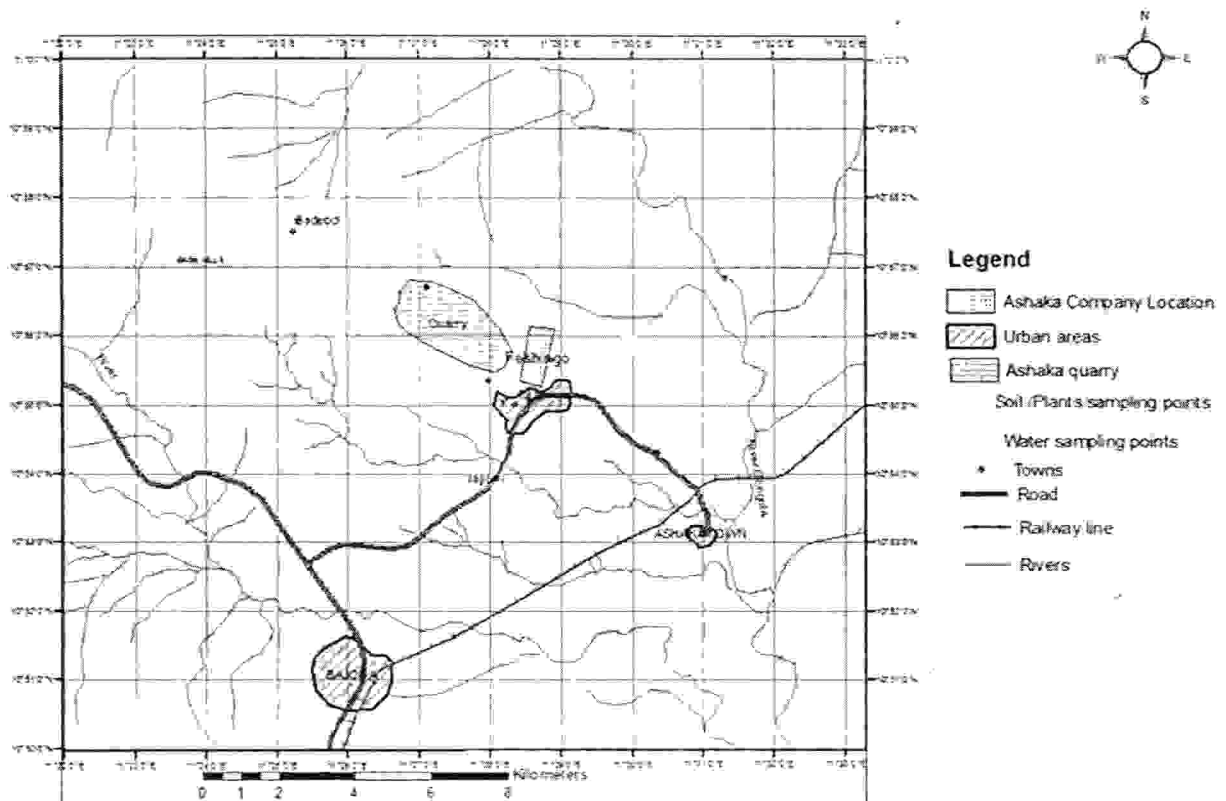


Fig. 1: Map of Ashaka and Environs

Topography and Drainage

The area is drained by River Gongola and its tributaries and the flow is NE-SW obeying the topography of the area. The northern site of Ashaka Cement Factory is marked by high relief rising steeply, from about an elevation of 255m above sea level over a distance of 2.5km (Bassey *et al.*, 2006). This forms a very steep scarp as exemplified in the Gongila Village, from where it slopes gently southward (Bassey *et al.*, 2006).

Climate and Vegetation

The area studied is characterized by two seasons: the rainy season and the dry season. On the basis of the topographic considerations the climate of the area belongs to the sub-Saharan zone (Obaje, 2009). The vegetation consists of abundant continuous tall grasses and thick tree cover with sporadic thorny bushes, green vegetation occurs along River channels. According to (Adefila *et al.*, 2009) the type of soil in the study area is closely related to the parent rock. Where the parent rock is homogenous, relatively simple soil associations are recognized. The shale give rise to grey heavy loams and clay soil derived from homogenous mudstone to give rise to olive brown clay Loam. Sandstones give rise to sand and loamy sand. The dominant soil type is grey mottled, sands and loams with some grey clay. The surface texture of the soil in Ashaka factory area ranged from, Loamy Sand (LS), Loam (L), Sandy Loam (SL), Sandy Clay Loam (SCL) and Sandy Clay (SL) with associated ammonites (Adefila *et al.*, 2009).

Geology and Stratigraphy of Ashaka Area

The Ashaka area is underlain by two main geologic formations: the Bima Sandstones and Gongila Formation both deposited in contrasting geologic environment and the recent alluvium of the Gongola River (Fig. 2). The Yolde formation, which is supposed to be between the two formations, is not distinguishable, and presumed to lie between them. According to Carter *et al*, (1963), the Bima Sandstone is the oldest known cretaceous rock in the area. The Bima Formation varies in age from upper Aptian to Middle Albian and rest unconformably on the uneven surface of the basement complex. The sandstones are medium to coarse grained, feldspatic and commonly coarsely cross-bedded. The outcrops are traversed by NE-SW trend. Top sections of the sandstones are highly ferruginized, sandstone beds are massive and in some places the thickness of about 250m has been exposed. The Bima Sandstone has total thickness of about 2,961m (Carter *et al*, 1963). The type locality of Bima Sandstone is the Bima hill. The Yolde Formation is a variable sequence of sandstone and shale which mark the transition from the continental Bima Sandstone to the marine Gongila Formation. The Yolde Formation is not clearly exposed in the study area. The formation is defined by the first disappearance of sandstone and commencement of the limestone-shale deposition. Yolde Formation is characterized by rapid alternation of sandy siltstones with silty-shales and fine sandstones.

The Gongila formation outcrops in the Ashaka Cement Factory quarry. The outcrop displays 12m of limestone and overlain by 25m of clay (Carter *et al*, 1963; Benkhil, 1989). The age of Gongila formation is from lower Turonian to upper Santonian. Okosun and Liebau, (2001) described the sequence as calcareous beds and clayey shales with a number of thin inter-bedded limestones. Fossil found in this formation are Ammonites, Gastropods, Branchiopods and other micro-fossils. The Alluvium of the Gongola River consists of silts and clayey silts, clays, sand and gravels. The sediments are immature and poorly sorted. The meandering nature of the river channels, means discontinuous bands of the different sediments are likely at all level of the Alluvium (Adegoke *et al.*, 1978; Obaje, 2009).

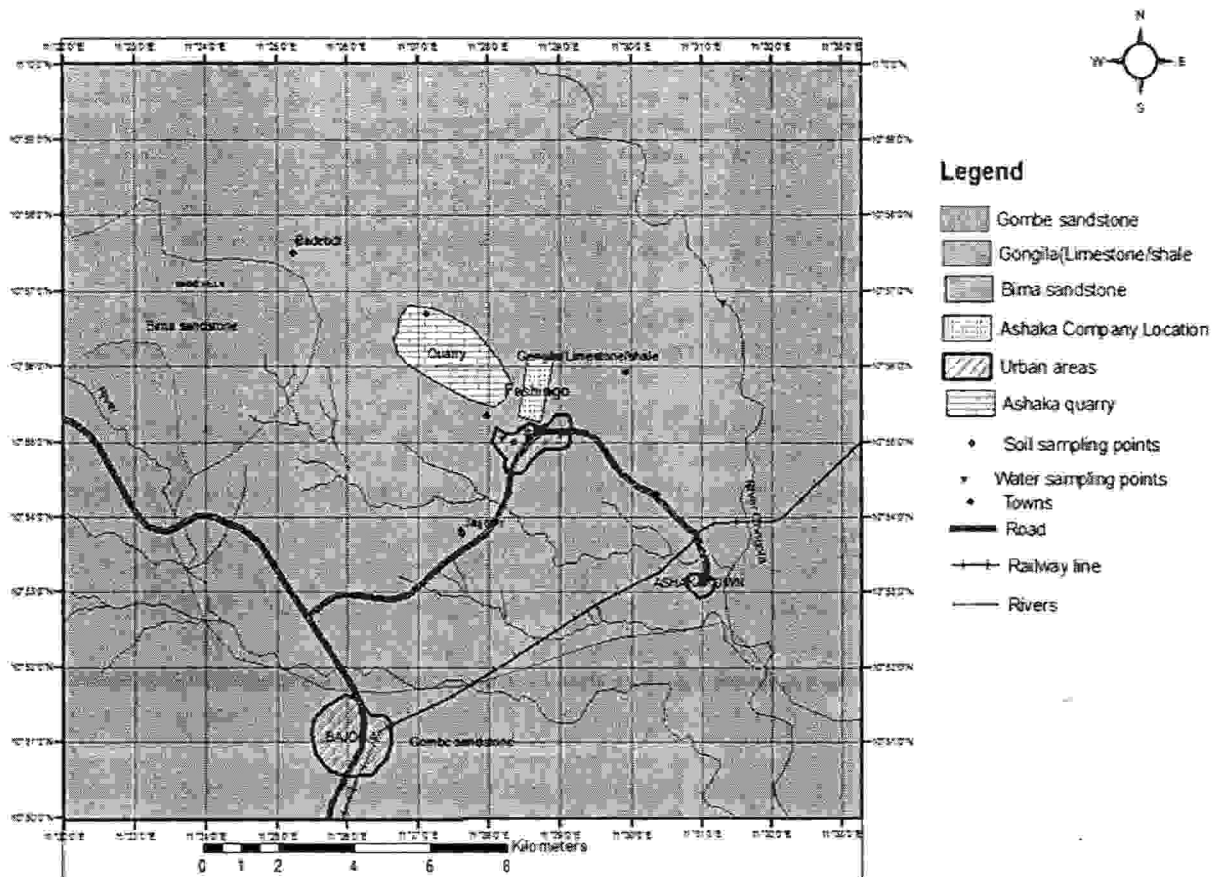


Fig. 2: Geology map of Benue Trough showing Ashaka Limestone Quarry

2.0. Materials and Methods

Sampling

A total of 35 water samples were collected from different sources such as hand dug-wells, surface water, boreholes, waste water and mine pond in the vicinity of Ashaka cement factory and subjected to water quality analyses. Also, 5 control samples were collected far away from the cement factory and subjected to water quality tests. The water sampling was carried out for both dry and rainy seasons in order to have an idea of the temporal and spatial variation in the physico-chemical and bacteriological characteristics of water in the area. Insitu test was made in the field for conductivity, pH, turbidity and Temperature using Hanna water proof EC/TDS conductivity meter, Hanna PHeP pocket pH tester, Hanna LP 200 turbidity meter and Mercury thermometer respectively. The cations and anions were analyzed in the laboratory using Inductively Coupled Plasma-Optical Emission spectrometer (ICP-OES) Model-Optima 200. The analytical procedures followed the APHA (2008) standard for analyzing water and waste water. The concentration of the analyzed physical, chemical and bacteriological parameters were in dry and rainy seasons were compared with the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO).

3.0. Results and Discussion

The statistical summary of the physico-chemical and bacteriological concentration of the water samples analyzed are contained in Table 1 for both dry and rainy seasons. A closer look at Table 1 shows that the concentration of all the physical and bacteriological parameters as well as some chemical parameters had higher concentration in dry season than in rainy season and this may be attributed to the dilution coming from rainfall.

Physical Parameters

The pH is a water quality parameter used to monitor pollution in water and it ranged between 6.5 to 8.5 for potable water (WHO, 2008). The pH at the dry season varied from 6.70 to 9.80 with a mean value 8.25 while the rainy season pH ranged from 7.00 to 7.90 with an average value of 7.45 (Table 1). These result by implication means that the pH in the area tends towards alkalinity and neutrality during the dry and rainy seasons. The dissolution effect of rainfall may be responsible for the reduction in the basicity of the soil/aquifer media in the course of groundwater migration. The concentration of electrical conductivity is a function of dissolved solid in water. The value of electrical conductivity for the dry season ranged between 70.0-1180.0 μ s/cm with a mean conductivity values of 625.0 μ s/cm and between 60.0-760.0 μ s/cm with an average value of 410.0 μ s/cm for the rainy season. The conductivity value during the rainy season falls below the maximum permissible limit of 1000.0 μ s/cm recommended by the Nigerian Standard for Drinking water Quality (NSDWQ, 2007). Some locations have their concentration slightly above the permissible limit for the dry season. The concentration of total dissolved solid (TDS) in the dry season varies from 42.0 mg/l to 708.0 mg/l with a mean concentration of 375.0 mg/l while the rainy season concentration ranges from 20.0 mg/l to 360.0 mg/l with an average concentration of 190.0 mg/l. The values of TDS were below the permissible value of 500.0mg/l in the rainy season sampling and this may probably be due the dilution effect of rain water. The approximate values of TDS can be determined by multiplying the corresponding conductivity values by a factor of 0.65 (Olasehinde *et al.*, 1998). The turbidity values ranged from 0.0-480.0 NTU with a mean value of 240.0 NTU for the dry season and between 0.0-168.0 NTU with an average value of 84.0 NTU for the rainy season as against the maximum permissible limit of 5.0NTU. The temperature varies from 26.6^oC to 27.9^oC with a mean temperature of 26.8^oC for the rainy season while in the dry season, the temperature rise from 31.1^oC to 42.1^oC with an average temperature of 36.6^oC (Table 1). The colour of the water ranged between 7.00 to 25.00 TCU with a mean value of 16.00 TCU for the dry season and the mean value exceed the maximum allowable limit of 15.00 TCU (NSDWQ, 2007). Studies have shown the low pH and elevated temperature enhances the toxicity and mobility of heavy metals while turbidity affects the colour of water (Amadi *et al.*, 2010).

Bacteriological Parameters

The total coliform and faecal streptococci were not determined in the rainy season in all the locations, while in the dry season, the concentration of total coliform varied from 6.0 to 96.0 cfu/100ml with a mean value of 51.0 cfu/100ml (Table 1) as against the maximum permissible limit of 10.0 cfu/100ml (NSDWQ, 2007). The faecal streptococci had concentration ranging from 0.0 to 29.0 cfu/ml with an average concentration of 14.5 cfu/ml (Table 1) as against the recommended value of 0.0cfu/ml (NSDWQ, 2007) and this implies that the water in the area is poor bacteriologically. The concentration of total coliform and faecal streptococci in most locations exceed the maximum permissible limit which is an indication of faecal contamination of the water sources in the area. Faecal indicator bacteria are present in human and animal faeces and are main cause of water borne or urinary tract infections such as cholera, diarrhea and meningitis. It also causes acute renal failure and haemolytic anaemia in adults as well as morbidity and mortality among children (Amadi, 2009; Egharevba *et al.*, 2010).

Table 4.1: Summary of the dry and rainy season water samples

Parameters (mg/l)	Dry Season			Rainy Season		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Colour	7.00	25.00	16.0	0.00	0.00	0.00
Temp. (°C)	31.10	42.10	36.60	26.60	26.90	26.75
pH	6.70	9.80	8.25	7.00	7.90	7.45
EC (µs/cm)	70.0	1180.00	625.0	60.00	760.00	410.00
TDS	42.0	708.00	375.0	20.00	360.00	190.00
Turbid. (NTU)	0.00	480.00	240.0	0.00	168.00	84.00
TC (cfu/100ml)	6.00	96.00	51.0	0.00	0.00	0.00
FS (cfu/ml)	0.00	29.00	14.50	0.00	0.00	0.00
Sodium	0.00	187.00	93.50	38.00	200.00	119.00
Potassium	2.50	68.40	35.45	2.40	12.70	7.55
Calcium	7.32	185.40	96.36	128.50	227.00	177.75
Magnesium	4.27	210.00	107.14	6.60	21.60	14.10
COD	18.0	35.00	26.50	17.00	48.20	32.60
Chloride	20.0	317.00	168.50	22.00	380.00	201.00
Sulphate	6.82	328.50	167.66	206.50	780.00	493.25
Phosphate	0.17	17.50	8.833	0.184	3.882	2.033
Ammonia	0.00	0.12	0.60	0.00	0.12	0.60
Bio carbonate	101.00	352.0	226.50	12.50	256.00	134.25
CaCO ₃	86.00	350.0	218.0	326.00	1550.00	938.00
Nitrate	0.63	13.60	6.815	0.25	30.30	15.275
Nitrite	0.00	21.50	10.75	0.00	0.00	0.00
Aluminium	0.00	8.55	4.275	0.02	0.11	0.065
Flouride	0.00	2.44	1.22	0.35	0.87	0.61
Lead	0.003	0.06	0.0315	0.03	0.283	0.157
Cadmium	0.006	0.53	0.268	0.005	0.02	0.0125
Zinc	0.003	2.11	1.057	0.002	0.155	0.079
Copper	0.002	0.65	0.326	0.002	0.15	0.076
Arsenic	0.004	0.052	0.028	0.004	0.061	0.033
Nickel	0.003	0.06	0.0315	0.004	0.0261	0.015
Chromium	0.00	0.00	0.00	0.031	0.436	0.234
BOD	0.00	0.00	0.00	5.00	58.00	31.50
DO	4.25	7.25	5.75	10.00	22.00	16.00
Manganese	0.008	90.00	40.004	0.002	0.052	0.027
Carbonate	0.38	166.00	83.19	69.00	205.00	137.00
Iron	0.32	1.44	0.88	0.02	3.30	1.66

Chemical Parameters

The concentration of sodium varies from 0.0-187.0 mg/l with a mean concentration of 92.5 mg/l for the dry season and 38.0-200.0 mg/l and an average value of 119.0 mg/l for the rainy season (Table 1). Unlike the physical and bacteriological parameters discussed, sodium has higher concentration in rainy season than in dry season which may be due to urban run-off. (Adelana and Olasehinde, 2003). The value of potassium ranged between 2.50-68.40 mg/l with an average 35.45 mg/l for the dry season as against 2.40-12.70 mg/l and a mean value of 7.55 mg/l for rainy season. The values of the alkali metals (sodium and potassium) are within the permissible limit of 200.0mg/l and 100.0mg/l (WHO, 2008). During the dry season, calcium ranges from 7.32-185.40 mg/l with a mean value of 96.36 mg/l while in the rainy season, calcium concentration varied between 128.50-227.00 mg/l with an average value of 177.75 mg/l (Table 1). The high concentration of calcium during the rainy season is probably due to the dissolution of host rock CaCO_3 by water. Magnesium concentration varied between 4.27-210.00 mg/l with a mean value of 107.14 mg/l during the dry season and ranged between 6.60-21.60 mg/l with an average value of 7.55 mg/l for the rainy season (Table 1). The concentration of sodium and calcium were higher during the rainy season than dry season while the reverse was observed for potassium and magnesium. This implies that the dilution by water of Na^+ and Ca^{2+} ions are faster than K^+ and Mg^{2+} . The concentration of Ca^{2+} and Mg^{2+} in water is responsible for water hardness and their concentration implies that the water in the area is soft. Calcium is an essential element for the formation of strong teeth and bone and its presence in water at higher concentration does not pose any problem. The concentration of the major cations (Na^+ , Ca^{2+} , K^+ and Mg^{2+}) in the various sources sampled falls below their respective permissible limit thereby indicating no pollution by major cations.

Chloride concentration for the dry season varied between 20.00-317.00 mg/l with a mean value of 168.50 mg/l while in rainy season, the values ranged between 22.00-380.00 mg/l with an average value of 201.00 mg/l (Table 1). The results show that chloride concentration in some locations in both seasons exceed the recommended maximum permissible limit of 250.00 mg/l (NSDWQ, 2007). High chloride concentration in groundwater in areas not close to the sea is attributed to urban pollution (Amadi *et al*, 2012). The concentration of sulphate ranged from 6.82-328.50 mg/l with a mean value of 167.66 mg/l for the dry season and between 206.50-780.00 mg/l with an average value of 493.25 mg/l for the rainy season (Table 1). The high sulphate concentration in the area may be due to bedrock dissolution in the area. The rock-type in the area consists of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and the minerals in the rock are high soluble in water. By means of bedrock dissolution in the course of rock-water interaction, the water is enriched by sulphate. Also urban pollution due to various anthropogenic activities in the area can result to high content of sulphate in water. The concentration bicarbonate varied between 101.00-352.00 mg/l with a mean value of 226.50 mg/l for dry season and between 12.50-256.00 mg/l with an average value of 134.25 mg/l for the rainy season (Table 1). High concentration of bicarbonate (HCO_3^-) in water is due to dilution effect of water on bedrock in the course of migration. The concentration of calcium carbonate ranged between 86.00-350.00 mg/l with a mean value of 218.00 mg/l for dry season and between 326.00-1550.00 mg/l with an average value of 938.00 mg/l (Table 1). Similarly, the concentration of carbonate varied between 0.38-166.00 mg/l with a mean value of 83.19 mg/l for dry season and 69.00-205.00 mg/l with an average value of 137.00 mg/l. Calcium carbonate (CaCO_3), a highly soluble rock is a major lithology in the area and this explains the enrichment calcium, carbonate and bicarbonate in the water from the area especially during the rainy season.

The mean concentrations of nitrate for dry and rainy season are 6.82 mg/l and 15.28 mg/l respectively. Similarly, the mean value of nitrite for dry season is 10.75 mg/l while in the rainy season, no nitrite was detected. The mean concentrations of phosphate for dry and rainy seasons are 8.83 mg/l and 2.03 mg/l respectively while that of ammonia for dry and rainy seasons were 0.60 mg/l and 0.12 mg/l respectively. These concentrations are within the permissible limit of NSDWQ (2007). According to Tredoux (2004) and Dan-Hassan *et al.*, (2012), high nitrite, nitrate and phosphate concentration in groundwater can be natural through bedrock dissolution and weathering processes or anthropogenic via industrial and agricultural activities. The concentrations of nitrate falls below the permissible limit of 50.0 mg/l (NSDWQ, 2007) while the concentration of nitrite in the dry season in most locations exceed the maximum permissible limit of 0.2 mg/l (NSDWQ, 2007). High nitrate and nitrite concentration in drinking water causes cyanosis and asphyxia (blue-baby syndrome) in infants less than three months (Dan-Hassan, 2012). It is also known as infant methaemoglobinaemia (Stadler, 2005; Amadi, 2010). Fluoride concentration for dry season varied between 0.0-2.44 mg/l with a mean value of 1.22 mg/l as against the maximum permissible limit of 1.5mg/l (WHO, 2008) while in the rainy season, the values ranged from 0.35-0.87 mg/l with an average value of 0.61 mg/l. Fluoride content below 1.5mg/l is beneficial in the formation of strong tooth and bone while in higher concentration exceeding 1.5mg/l, it causes teeth fluorosis (dark-brown colouration in teeth) as well as skeletal fluorosis (deformation of the bone). The enrichment of fluoride in the area may be geogenic through chemical weathering or anthropogenic human actions such as application of fluoride rich fertilizer and discharge of untreated industrial effluent (Aminu and Amadi, 2014).

Dissolved Oxygen (DO) represents the amount of oxygen required to oxidize the organic matter content in the water samples to carbon dioxide and water (Egharevba *et al.*, 2010). The value of DO for rainy season ranged between 10.00-22.00 mg/l with an average value of 16.00 mg/l and 4.25-7.25 mg/l with a mean value of 5.75 mg/l for the dry season (Table 1). The biochemical oxygen demand (BOD) is the amount of oxygen that bacteria will consume while decomposing organic matter into Carbon dioxide, water and ammonia (Ademoroti, 1996; Amadi, 2010). The BOD concentration for dry season was not detected (Table 1) while in rainy season, it ranged between 5.00-58.00 mg/l with a mean value of 16.00 mg/l. This concentration is higher than the acceptable limit of 6.00 mg/l (WHO, 2006). The chemical oxygen demand (COD) determination is a measure of the oxygen equivalent of the portion of organic matter in water that is susceptible to oxidation by a strong chemical oxidant. It determines the amount of oxygen required for oxidation of organic and inorganic matter in water. The concentration of COD in the dry season ranged from 18.00-35.00 mg/l with a mean value of 26.50 mg/l while in the rainy season, the values varied between 17.00-48.20 mg/l with an average value of 32.60 mg/l. The COD concentration in both seasons exceed the maximum recommended value of 10.00 mg/l by WHO (2006) and NSDWQ, (2007). High concentration of COD in water is an indication of pollution by an oxidizable organic and inorganic solid waste leachate (Alao and Amadi, 2012).

Heavy metals are metallic elements that have relatively high density and are toxic at low concentrations. It refers to chemical elements with a specific gravity that is at least 5 times the specific gravity of water. The heavy metals analyzed include cadmium, manganese, lead, nickel, chromium, copper, zinc, arsenic and iron. The concentration of cadmium ranged between 0.006-0.53 mg/l with a mean value of 0.268 mg/l for the dry season and 0.005-0.02 mg/l with an average value of 0.0125 mg/l for the rainy season. The obtained values are higher

than the maximum permitted value of 0.003 mg/l for potable water (NSDWQ, 2007). Cadmium is toxic to the kidney and liver and results indicates cadmium enrichment in the water. Cadmium is used as pigments in plastics, batteries, electroplating and in electronic components (Amadi *et al.*, 2013). Manganese ranged between 0.008-90.00 mg/l and 40.004 mg/l as mean for the dry season while in rainy season that value falls as low as 0.002-0.052 mg/l with an average value of 0.027 mg/l (Table 1). The recommended maximum allowable limit for manganese by NSDWQ (2007) and WHO (2008) is 0.2 mg/l. High concentration of manganese in drinking water causes neurological disorder in man (Amadi *et al.*, 2010). The presence in water is likely from the limestone mining and processing in the area.

Concentration of copper varied from 0.002-0.65 mg/l with a mean value of 0.326 mg/l for dry season and 0.002-0.15 mg/l with an average value of 0.076 mg/l for rainy season (Table 1). Copper has a lot of applications ranging from electrical wiring, roofing sheets, alloy pigments, cooking pots, electroplating to insecticides and wood preservation. It is added to animal feeds and fertilizer as a nutrient to support plants and animal growth (Pascual *et al.*, 2004). The measured copper concentration in the study area falls with the permissible limit of 1.0 mg/l recommended by (WHO, 2006). High concentration of copper in water leads to gastrointestinal disorder (NSDWQ, 2007). Chromium concentration is in the order of 0.031-0.436 mg/l and 0.027 mg/l for the rainy season while in the dry season, it was not detected. The value in some location in the rainy season exceeds the acceptable limit of 0.05 mg/l by NSDWQ (2007). Enrichment of chromium in water causes cancer (Aboud and Nasndini, 2009) and their presence in the water are imprints of the exploitation of limestone and gypsum in the area. These heavy metals were absent in the control samples collected far away from the mining area and it is a confirmation that limestone mining and processing in the area accounts the heavy metal pollution in the various water sources (Surface water, hand-dug well, mine-pond, boreholes and waste water) from Ashaka and environs.

Nickel measured concentration for dry season varied from 0.003-0.006 mg/l with a mean value of 0.0315 mg/l and 0.004-0.0261 mg/l with an average value of 0.015 mg/l for rainy season. Nickel is a major component in most alloys, batteries and electronic products (McAllister *et al.*, 2005). These concentrations in some location exceed the maximum permissible limit of 0.02 mg/l (NSDWQ, 2007) and enrichment of nickel in drinking water is a possible cause of cancer in man. Lead is a non-essential element for plants and animals and is toxic in small concentration of lead in dry season were between 0.003-0.006 mg/l with a mean value of 0.0315 mg/l while in rainy season. it falls between 0.03-0.283 mg/l with an average value of 0.157 mg/l (Table 1). The acceptable maximum limit for lead is 0.01 mg/l (NSDWQ 2007; WHO, 2008). High lead concentration in water leads to anaemia both by impairment of haemobiosynthesis and acceleration of red blood cell destruction. It also reduces sperm count, damages kidney, liver, blood vessels and other tissues in human (Anglin-Brown *et al.*, 1995) and their presence in water are signatures of the impact of Ashaka limestone mining and processing on water quality.

Arsenic concentration for dry season varied between 0.004-0.052 mg/l with a mean concentration of 0.028 mg/l and 0.004-0.061 mg/l with an average value of 0.033 mg/l as against the permissible limit of 0.01 mg/l (NSDWQ, 2007). Arsenic is highly carcinogenic and has no nutritional value for plants and animal (Amadi *et al.*, 2010). The concentration of zinc in dry season ranged between 0.003-2.11 mg/l with a mean concentration of 1.057 mg/l and 0.002-0.15 mg/l with an average concentration of 0.076 mg/l. These values fall below the

permissible limit of 3.0 mg/l by NSDWQ, (2007) and WHO, (2006). Zinc has no serious effect on humans and plants; it is an essential growth element for plants and animals (Preda and Cox, 2002). It is used in making alloys of brass and bronze. During the dry season iron concentration ranged from 0.32-1.44 mg/l with a mean value of 0.88 mg/l. In the rainy season, it varied between 0.02-3.30 mg/l with an average value of 1.66 mg/l. The recommended value for potable water is 0.3 mg/l (WHO, 2006; NSDWQ, 2007). High concentration of iron may be due to leachate from lateritic overburden in the course of chemical weathering of host rock. High concentration of iron in water does not have any health implication but the colour and taste of the water is effected (Amadi and Olasehinde, 2010; Ammann *et al.*, 2012; Vinodhini and Narayanan, 2008).

The impact of anthropogenic activities domiciled in the area (cement factory) is responsible for the presence of these heavy metals in the water. Some of these metals are naturally induced into the water in the course of bedrock dissolution and chemical weathering processes while others are induced into the environment in form of effluents that later find its way into the groundwater system. The following metals: cadmium, zinc, copper, nickel and manganese have higher concentration in the dry season compared to rainy season. Amadi *et al.*, (2010) suggest that concentration of heavy metals is higher in dry season than rainy season due to urban runoff and dilution effect subject to the prevailing hydrogeological conditions. The heavy metal enrichment in groundwater during rainy season is made possible through bedrock dissolution, leaching/infiltration through a porous permeable underlying formation and aids the introduction of demobilized metals into the groundwater system especially in areas with shallow water table and unconfined aquiferous zone. The high concentration of heavy metals in the area is unconnected with the extraction of limestone in the area for cement production. The discharge of untreated effluent from the company into the environment is a possible source of these metals in the groundwater system.

Hydrochemical Facies Analysis

This method was devised by Piper and Durov to outline certain fundamental principles in a graphic procedure which appears to be an effective tool in separating analytical data for critical study with respect to sources of the dissolved constituents in water. Both diagrams consist of three parts: two common triangles at the base with a diamond-shaped diagram in the middle for Piper (Fig. 4) and a square in the middle for Durov (Fig. 5). The diagrams illustrate the relative concentration of cations (left diagram) and anions (right diagram) in each sample. The concentration of 8 major ions (Na^+ , K^+ , Mg^{2+} , Ca^{2+} , Cl^- , CO_3^{2-} , HCO_3^- and SO_4^{2-}) are represented on the diagrams by grouping the K^+ with Na^+ and the CO_3^{2-} with HCO_3^- , thus reducing the number of parameters for plotting to 6. On the diagrams, the relative concentration of the cations and anions are plotted in the lower twin triangles, and the resulting two points are extended into the central field to represent the total ion concentrations. The degree of mixing between freshwater and saltwater can also be shown on the diagrams. The Piper and Durov diagrams are used to classify the hydrochemical facies of the groundwater samples according to their dominant ions. The water in the area are: Ca-Mg-SO₄, Ca-Mg-HCO₃ and Ca-Mg-SO₄-HCO₃ and indication that the water type in the area is from the local geology of the area.

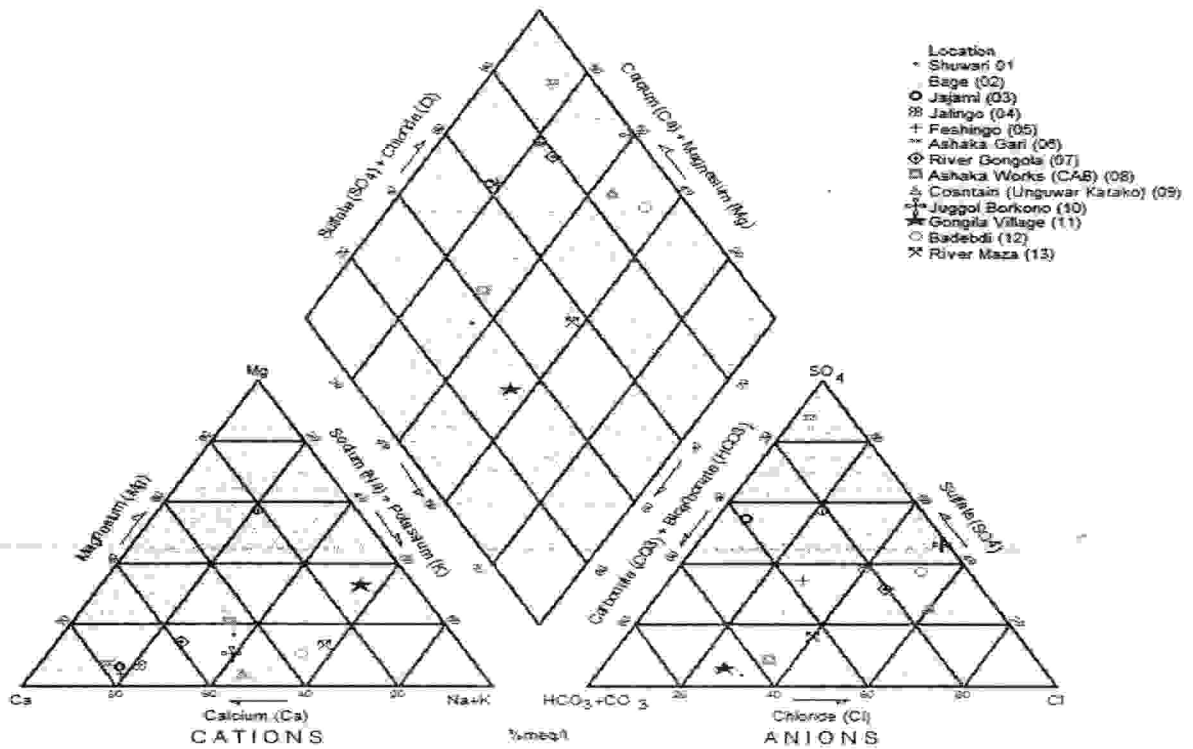


Fig. 4: Piper diagram for Ashaka and environs

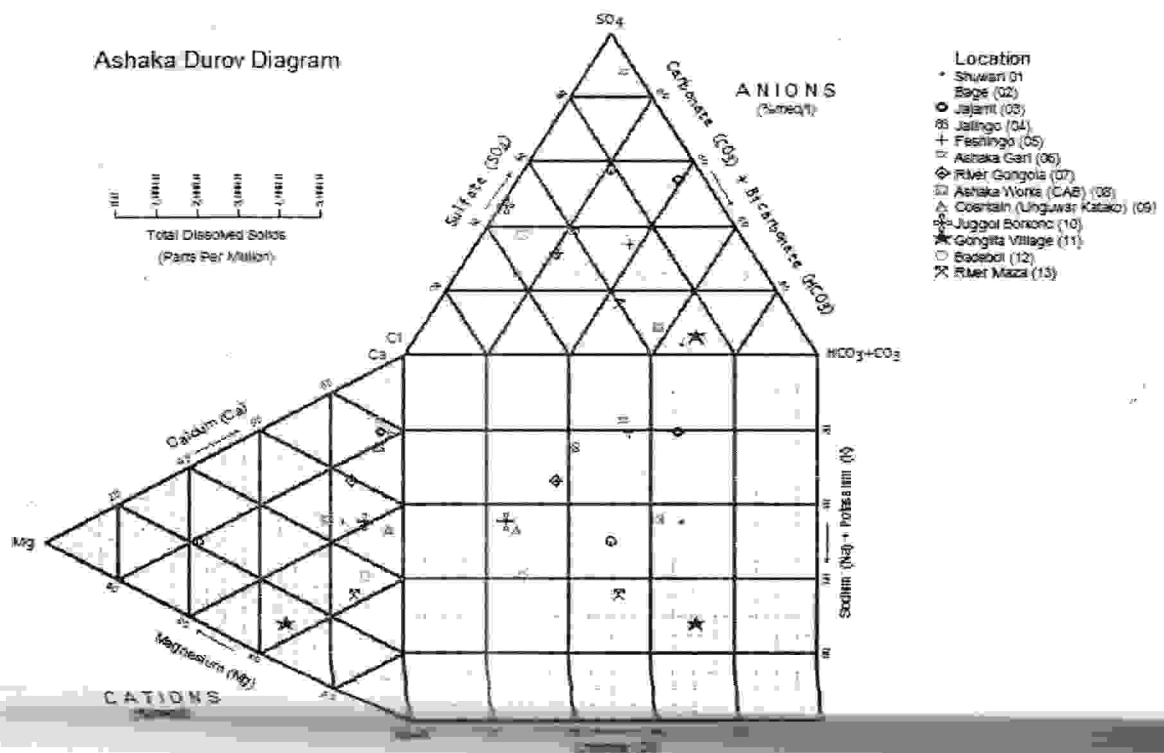


Fig. 5: Durov diagram for Ashaka and environs

Conclusion and Recommendation

The present study has established that the water pollution in the vicinity of Ashaka cement factory has both natural and artificial imprints. The high concentration of Carbonates and bicarbonates in the water are naturally induced due to bedrock dissolution and chemical weathering while fluoride and heavy metal enrichment in the water is anthropogenic via mining and processing of cement in the area. The water type in the area is Ca-Mg-SO₄, Ca-Mg-HCO₃ and Ca-Mg-SO₄-HCO₃, and this implies that the water in the area derived their source from the lithology. The following heavy metals: Cd, Mn, Fe, Cu, Ar, Ni, Pb, Cr and F were identified in the water within the surrounding of the cement factory. However, these metals were virtually absent in the samples collected far away from the vicinity of the cement factory. This is an indication that their presences are anthropologically induced due to mining and processing of limestone and gypsum in the area. The dumping of untreated effluent from the cement factory into the surrounding rivers may be responsible for the accumulation of the metals in the water. The degree of accumulation of the metals are in the order of Mn > F > Cd > Fe > Cu > As > Pb > Ni > Cr. This implies that Mn has the highest water pollution index while Cr has the least water pollution index. Government all levels should enforce the treatment of industrial effluent before discharging them into the environment. Alternative source of drinking water should be provided to the host communities where their surface and shallow groundwater have been polluted by effluent from the cement factory. Periodic assessment of the various water sources should be undertaken in the area in order to adequately monitor the pollution status of the water resources in the area. The management of Ashaka cement factory should ensure that industrial best practices are employed in their daily operation in the area.

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