British Journal of Applied Science & Technology
8(3): XX-XX, 2015, Article no.BJAST.2015.206
ISSN: 2231-0843

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Borehole Annulus-Filling Materials and Enrichment of Heavy Metals in Eocene-Palaeocene Aquifer Systems in Awka, Southeast Nigeria

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Authors' contributions

The three authors collaborated to do this study. Author KKN as the lead author, designed the study, managed the analyses of the study and related literature reviews, and wrote the first draft of the manuscript. Authors OIC and LOO managed the laboratory and statistical analyses as well as related literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/14955
Editor(s):
(1)
(2)
Reviewers:
(1)
(2)
(3)
Complete Peer review History:

Original Research Article

Received 29th October 2014
Accepted 26th March 2015
Published 9th April 2015

ABSTRACT

Contamination of groundwater resources is more often associated with the infiltration of pollutants from anthropogenic activities such as waste dump sites and industrial effluents. Similar to this, reported results may be limited in its accuracy by poor sampling and analytical techniques. This study is interested in the role of geologic materials. Geologic materials, whether in-situ host rock or transported materials play a massive role in determining the quality of groundwater in any geosystem. A time-lapse evaluation of groundwater quality in Awka shows a progressive deterioration as a result of increasing enrichment in heavy metals. It is noted that Vanadium, Manganese, Arsenic and Copper increased the most over the 1993 to 2013 period under consideration. Host-rock geochemistry discounts the dominant Imo Shale as a source of the contaminants. While recognising the likely infiltration of pollutants from other common sources, it is here suggested that the high concentration of heavy metals can also be the effect of weathering

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products and leachates that are being derived from heavy-metal-rich igneous rock aggregates that are commonly used as annulus-filling materials in borehole construction. This calls for a more in-depth study to understand the pollution network in order to evolve a coordinated approach to protect the groundwater system and save the populace from looming health and environmental hazards.

Keywords: Groundwater quality; heavy metals; borehole annulus-filling; Awka.

1. INTRODUCTION

One of the critical concerns of the residents of Awka Capital City and environs in Anambra State is the lack of safe and sustainable water supply. A great percentage of the population depends on self-help in order to make the vital resource of life available through the exploitation of groundwater, surface water bodies and rain water-harvesting. The acute need to provide water seems to have pushed every consideration for quality and acceptable best practices beyond the reasoning of the inhabitants. It is no longer absurd to see families and businesses scrambling to place orders from peripatetic vendors such as water tankers, wheel-cart pushers, bucket, kegs and sachet water hawkers. A disturbing factor is that a great number of the consuming public never gets to query the source and quality of the deliveries. The poor and inadequate water supply in Awka has a history.

Public water supply in Awka became comatose following the switch in the town's fortunes from a mere urban centre to the Capital City of Anambra State [1]. This change in administrative status and economic potentialities brought with it a sporadic increase in human population and placed enormous demands on available water resources. [2] noted that the population has increased by almost 300% from 61,200 in 1991 to over 181,790 in 2013, with about 29,503 households. Prior to that time, pipe-borne water that was sourced mainly from Imoka Water Works had to be rationed by the State Water Corporation among the residents along chaotically delineated zones. However, that arid-relief method collapsed completely in early 2002 following a protracted industrial action by the workers of the Anambra State Water Corporation. The long period of abandonment led to a myriad of ecological problems including severe gully erosion at the river-head and subsequent silting-up of the flow channels at the Imoka Water Works. Further downstream, high level of vandalism of equipment and facilities made the situation more sordid. Alas, the hope of early resuscitation of the Awka Water Scheme had been dashed by successive administrations in the State as other less relevant projects took the centre stage coupled with poorly coordinated public infrastructure development policies. [3] had examined the level of water demand and supply of the peri-urban communities of Awka Capital Territory and established a high level of water scarcity in the area at an alarming demand-supply gap of 48.9%. Apparently disillusioned by the seeming hopeless situation, the ingenuity of a desperate will to survive has led to an era of indiscriminate exploitation of groundwater through the drilling of boreholes and manual digging of water wells. Hydrogeological fieldwork indices suggest that one out of every ten homes in Awka is currently serviced by a groundwater abstraction facility; even as the number continues to grow. The wells are generally drilled by local and artisanal contractors who give little or no regards to scientific data that will be of relevance to aquifer and groundwater integrity.

Groundwater is thought to be a natural resource that is available to any one that has the means to access it. Comparatively, it is considered to be naturally protected and of better quality than either rain or surface water [4,5,6,7]. This assumption carries with it a potent danger of criminal neglect of acceptable best practices to protect this vital resource from the threats of irredeemable pollution and over-exploitation [8]. The natural quality of the groundwater is a function of its interaction with the host rock. Globally, groundwater contamination and pollution occur as a result of urban pollution, deleterious industrial discharges, agricultural activities, mining drainages and drilling practices.

It is often emphasised that borehole drilling can potentially introduce pollutants into the groundwater system. This could come from toxic drilling fluids, oil spills from drilling equipment, wellbore lining and annulus-packing materials. Poor professional input into the planning and development of boreholes has led to a rising wave of compromise and cost-cutting measures such that materials that pose risk to human health are being deployed for groundwater abstraction. For instance, there is an ill-informed preference of volcanic rock chips to river gravels as annulus filling materials. On their face value, these volcanic-rock derived aggregates could be potential sources of high levels of heavy metals such as Vanadium (V), Arsenic (As), Lead (Pb), Nickel (Ni) Chromium (Cr), Copper (Cu), Zinc (Zn), Manganese (Mn) and Cadmium (Cd) which can be of toxic risk when in contact with groundwater [9,10]. Since most residents of Awka rely almost entirely on boreholes for their daily supply of water, it is imperative to assess the quality of groundwater in the face of obvious abuses, unprofessional development and unbridled escalation of water boreholes.

2. THE STUDY AREA

Awka is the Capital City of Anambra State in the south eastern region of Nigeria. It was originally an urban town that served as the headquarters of Awka-South Local Government Area before it was elevated to a State capital following the creation of Anambra State on August 27, 1991. It is bound by latitudes 06º 06' N and 06º 15' N and longitudes 07º 05' E and 07º 15' E (Fig. 1) and lies within the humid tropical rainforest belt that is characterised by wet and dry climatic seasons [11]. Awka is generally known to have an average annual rainfall of 1478 mm. The temperature generally ranges from 27ºC to 28ºC in the months of July through December but could rise up to 35ºC between February and April [12].

In terms of topography, [2] observed that most of the area situates at an altitude of 300 m above sea level on the high plains of Mamu River with two major cuestas that trend in a North-South direction in the eastern and western axes forming the major relief features. The peak of the eastern ridges varies between 300 m to 350 m around NkwelleAwka and towards the Awka outer ring road. The lower western ridge may reach up to 150 m above the sea level at Ifite-Awka – Enugwu-Agidi and Amawbia axis. These undulations constitute part of the Awka-Orlu Cuesta. Awka area is drained by numerous rivers such as Ezu River, Imoka River, Ofia, Obizi, Obibia, Haba and Mamu. The area is currently undergoing a rapid surge in human population and economic activities which unfortunately is not matched with commensurate infrastructural development. The net effect is a ravenous exploitation of available resources including groundwater. Many residents of the town depend on shallow wells and surface water for their household water supply.

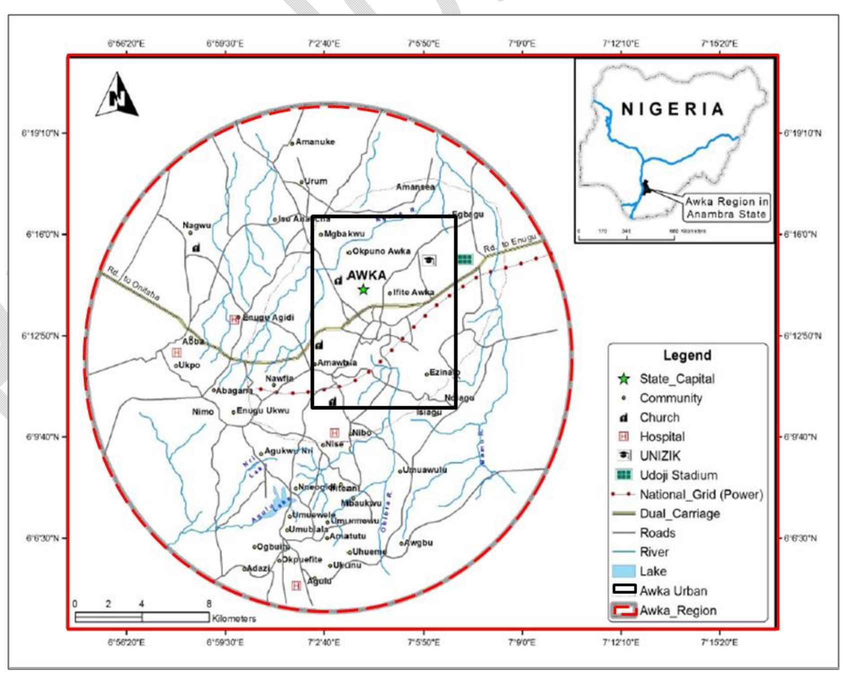

Fig. 1. Section map of Nigeria showing Awka capital city and adjoining communities
Source: [3]

2.1 Geologic Setting

Geologically, Awka lies mainly on the Palaeocene Imo Shale and Eocene Ameki Formation (Fig. 2) in the Anambra Basin.

Details of the regional geology abound in literature such as [13]. The Imo Shale as named is dominated by low permeability mudstones and constitutes an aquitard. In places where there are fingers of sandy units such as the Ifite-Awka Sand and Ebenebe Sandstone members, the Imo Shale may be seen as a local confinement for the aquifers. In such areas, aquifer depths are usually in the range of 20 m to 60 m with the uncertainty of their capacity to yield water in satisfactory quantities. The Ajali Sandstone can be penetrated at about 500 m beneath the Imo Shale and constitutes the deep aquifer system that is capable of sustainable water production. The Eocene Ameki / Nanka Sands comprise an upper lateritic sandy unit that is underlain by a thick succession of sands and sandstones. These often may occur with negligible layers of clay and gravels of various sizes. In the parts of Awka where there are outcrops of Ameki / Nanka Sands, depth to exploitable aquifer may range from 6.0 m to 35 min their shallowest and may exceed 168 m in their deepest settings. Thus, Awka is hydrogeologically configured into a multi-aquifer system. This consists of a shallow, unconfined aquifer system that is typically less than 60m with the risk of vulnerability to pollution as well as artisanal drilling abuse; and a deep, confined aquifer system which may range in depth from 180 m to 540 m [14].

3. METHODOLOGY

The study involved same-season field sampling of selected water boreholes and laboratory analysis of collected water samples.

3.1 Sample Collection and Analysis

Sampling and analytical techniques were in accordance with [15] and the procedures described in [16]. The water samples were taken from the study boreholes and stored in plastic bottles which had been washed and severally rinsed with earlier drawn water samples from the boreholes. Although routine water analysis tests were conducted to determine the levels of concentration of anions and cations, this however is not the subject of the present discussion. The analysis involved the use of Atomic Absorption Spectrophotometer

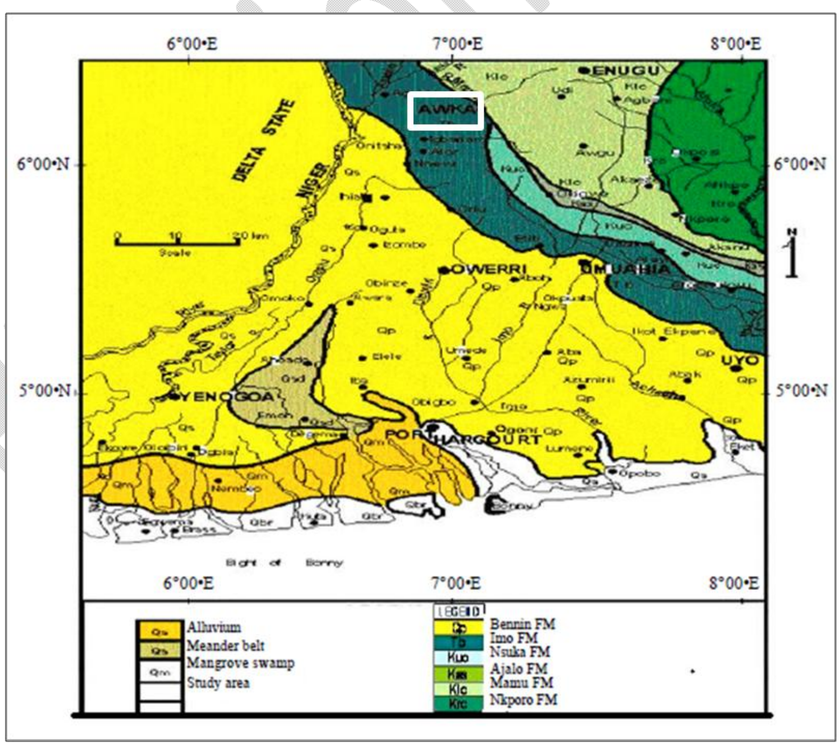

Fig. 2. Section geologic map of Nigeria showing the study area
Source: [14]

(Pye Unican 969) for the determination of heavy metals (HM) as demonstrated in [17]. The analytical workflow complied with acceptable best practices and operational guidance in the instrument's manual. The desk study involved comparison of the results with those obtained in same / contiguous boreholes in a 1993 groundwater quality monitoring exercise in the study area, as well as relevant rain water quality data [12]. Information on the possible sources of abnormal concentrations of some heavy metals were derived from published geochemical data of the in-situ Imo Shale [18] and those of the non-indigenous Abakaliki igneous rock [19] aggregates that are massively used in borehole construction in the area. The established time-lapse physical and chemical properties of groundwater in the area are based on the interpretation and correlation of the results of the laboratory findings.

4. RESULTS

Identified heavy metals (HMs) and their concentrations are illustrated in Fig. 3.

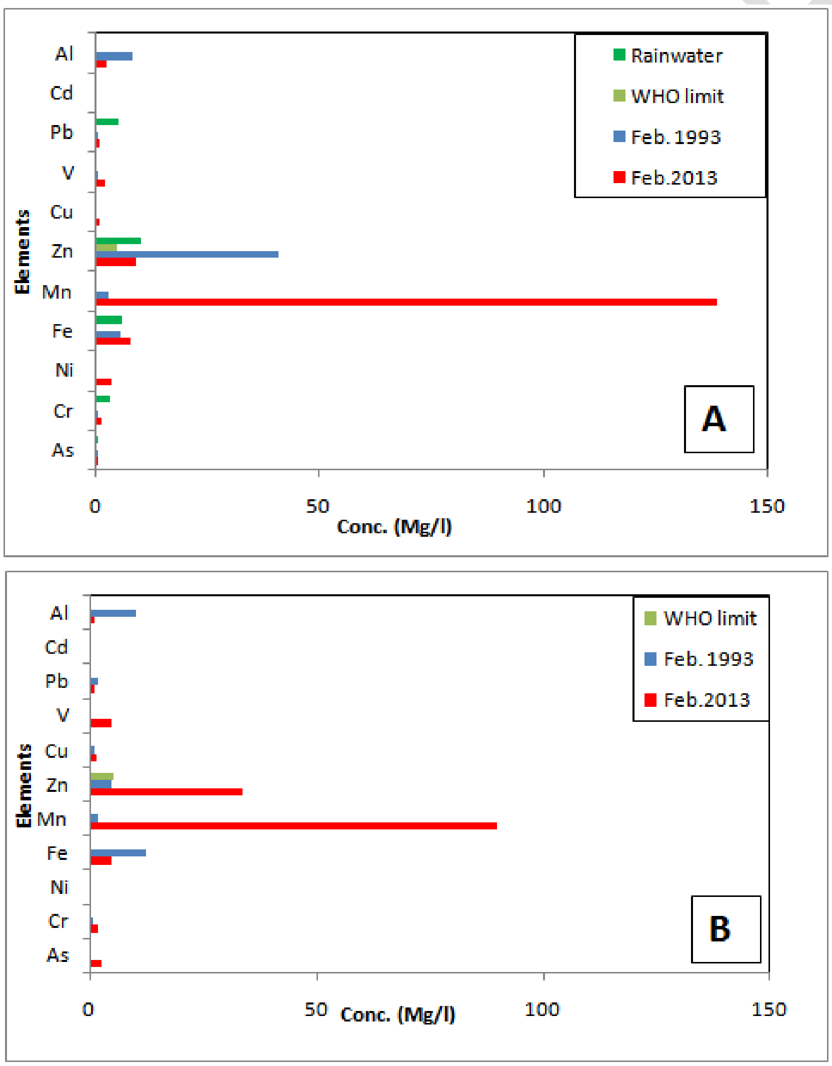

Fig. 3. Concentration of heavy metals in water samples sourced from the two study wells in 2013 (red bars) as compared with data in 1993 (blue bars). These are co-plotted with [22] limits (lemon bar) and rainwater data ([12]) in the area (green bar). There is a progressive increase in the concentrations of Al, V, Zn, Mn, Fe, Cr, and as over the 20 year period

On the plot are values for Aluminium (Al), Iron (Fe), Lead (Pb), Cadmium (Cd), Chromium (Cr), Copper (Cu) and Manganese (Mn). Others are Nickel (Ni), Vanadium (V) and Arsenic (As). Values of Mn in both wells analysed were 90 mg/l and 140 mg/l respectively which indicate that Mnhas the highest concentration. This is followed by Zn, Fe and V. A trend of increase in the concentration of some HMs is noted for the period under assessment. Between 1993 to 2013, the concentration of As increased by 78% from 0.42 mg/l to 0.75 mg/l in well A and from 0.24 mg/l to 2.65 mg/l representing 1004% in well B. Fig. 4 **Fig. 4**shows that the most progressive enrichment was for V, Mn and As while Fe, Ni and Al diminished.

4.1 Sources of Heavy Metal Enrichment

Naturally enriched rocks and primary ores are some of the common sources of abnormal concentrations of heavy metals in the environment [4,10]. The first consideration was to establish whether the heavy metals were derived from in-situ geologic sources. The geochemical properties of the in-situ Imo Shale has been analysed by [18] while [20] studied the Abakaliki volcanics. Similarly, [12] provides an update on the quality of rainwater in Awka and environs. These results are plotted in Fig. 5. The plot does not indicate significant concentration of heavy metals in the rain water data. Similarly, it shows that Imo Shale has very negligible concentrations of trace elements of interest with Cr and Ni as the highest concentration at 0.03 mg/l and 0.02 mg/l respectively. These are not high enough to constitute significant concentrations in the groundwater system. Having discounted Imo Shale as a possible source of the enrichment, the study concentrated on transported non-indigenous Abakaliki volcanic aggregate materials that are mostly used in annulus packing during borehole construction. As shown in Fig. 5, the concentration of Pb, V, Zn, Mn, Ni and Cr in Abakaliki volcanics are excessively high with V and Mn exceeding 600 mg/l and 1180 mg/l respectively.

5. DISCUSSION

In tropical environments, the concentrations of metals are strongly influenced by the geochemical characteristics of the bedrock and the nature of dominant weathering processes [20]. The major pathways for heavy metals are by sedimentation of particles and by sorption of dissolved metals from seepages. Most trace metals occur in solution as cations (e.g. Pb^{2+}, Cu^{2+}, Ni^{2+}, Cd^{2+}, Zn^{2+}) which become

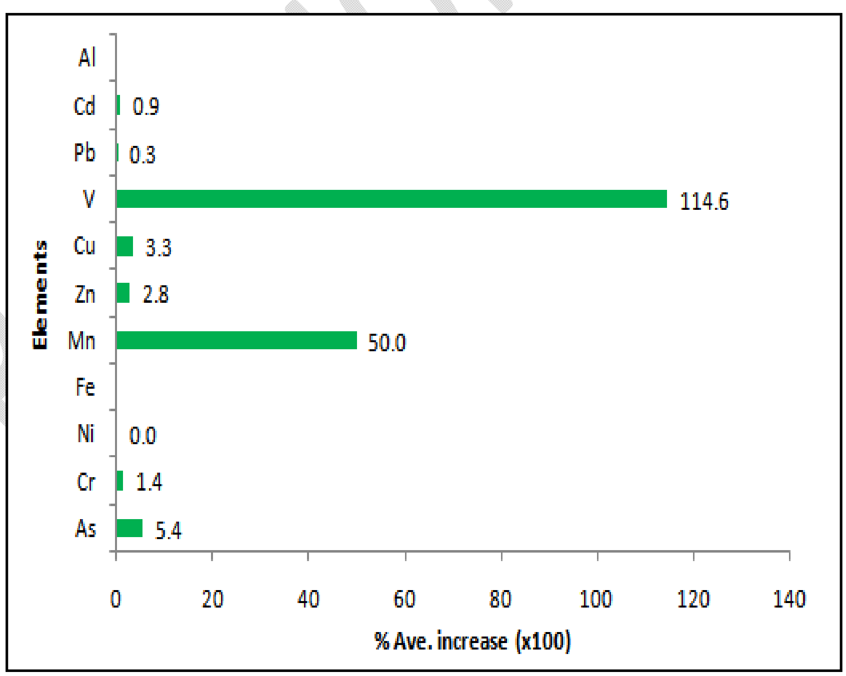

Fig. 4. Percentage average enrichment of heavy metals in Awka groundwater system between 1993 and 2013

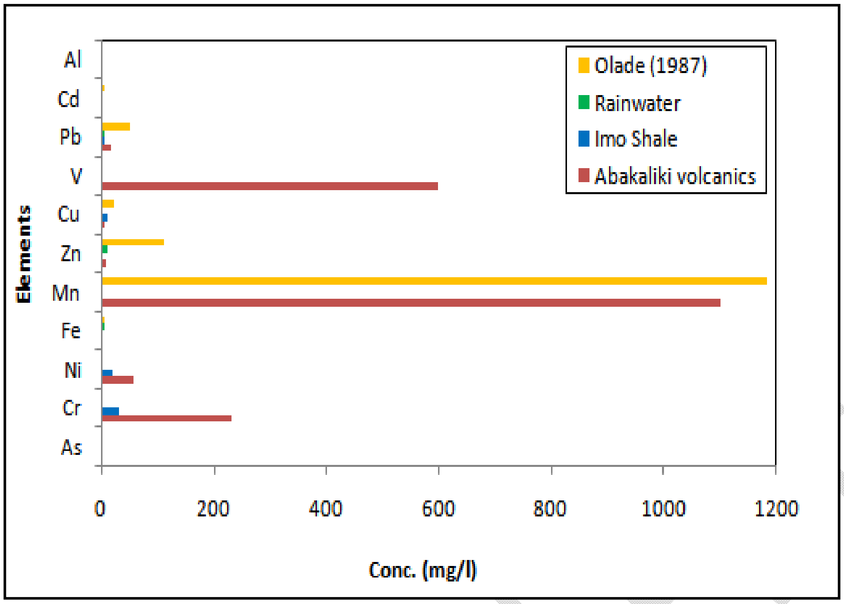

Fig. 5. Geochemical data for Imo Shale and Abakaliki volcanics. The volcanic rocks that serve as borehole annulus-filling materials are high in Pb, V, Zn, Mn, Ni and Cr

increasingly insoluble with increase in the pH of the system. The co-location of some of these metals can be indicative of their originating sources. For instance, cadmium, zinc and lead occur naturally in ores.

Unusual concentrations of heavy metals in groundwater systems are serious environmental and public health issues that continue to attract wide attention [21]. Among the heavy metals, Cd, V, Pb, Cu, Zn, Mn, Cr and As are observed to show progressive increase in their concentration levels in Awka groundwater systems and in most cases exceeding [22] recommended limits. A major health and environmental concern with this development is that even their low concentrations have the potential for strong toxicity. For instance, concentration of manganese that is greater than 0.05 mg/l may adversely impact on the color, odor and taste of the water. Long term consumption of manganese-contaminated water can have toxic effects on the nervous system [23] leading to hallucinations, forgetfulness, nerve damage and some sort of Parkinson syndrome especially among the elderly. Similarly, concentrations of zinc in excess of 5 mg/l will deteriorate the quality of water by giving it a chalky appearance and bad taste. Extensive intake of such zinc-contaminated water has health implications such as anaemia, damage to pancreas, reduced protein metabolism, respiratory disorders and arteriosclerosis [24].

The rapid increase in vanadium concentration by 115% is worrisome and is likely due to leachates from the igneous annulus filling aggregates and derived dust. When rocks that contain vanadium are broken down by weathering, vanadium gets into the groundwater as nano-size particles / ions that can bio-accumulate in living organisms until it reaches hazardous concentrations. Unhealthy accumulations of vanadium in humans may lead to several neurological disorders including paralysis, liver and kidney failures, respiratory challenges, DNA alteration and adverse effects on the reproductive systems [25]. Taking a look at Arsenic; Arsenic in drinking water is deleterious to human health and contaminates the groundwater through arsenic-rich rocks from which the water may have filtered. Its wide occurrence in groundwater in Bangladesh [26] contributed significantly to the wide global attention it has attracted which underscores the need for its assessment in aquifers systems worldwide. Chronic exposure to arsenic has been associated with several types of carcinogenic diseases. It is typical for high-arsenic groundwater to also reflect high iron and manganese concentrations. Long term intake of high concentrations of Cadmium has been linked with some cases of high blood-pressures, liver disease and nerve or brain damage [27]. Similarly, high levels of chromium in drinking water can cause respiratory problems, immune deficiency, birth defects, infertility and tumor formation [28]. Copper plays an important role in human nutrition but causes gastrointestinal disorder when taken in excess proportions [29]. Although significant concentration of Lead was not observed, it however should be noted that it has teratogenic effect [30]. Lead is carcinogenic, toxic to the nervous system and interferes with the metabolism of calcium and Vitamin D. Chronic exposure to lead can be hazardous to reproductive and renal systems as well as causing high blood pressure and anemia. At very high levels, lead can cause convulsions, coma and death in children.

6. CONCLUSION AND SUGGESTIONS

This work has evaluated the quality of groundwater systems in Awka and highlights their progressive enrichment in heavy metals over a period of time. Since the in-situ Imo Shale is not rich in heavy metals, the observed high concentrations of these heavy metals are thought to be as result of the weathering and leaching of volcanic aggregates that are mostly used in place of river gravels as borehole completion materials. While this sounds reasonable, it will be of benefit to consider other possible sources of groundwater contamination and more sampling density to minimize the uncertainty of the results and draw a more holistic conclusion. As a baseline study that has highlighted an evolving challenge, it is recommended that a policy aimed at dissuading unprofessional abstraction of groundwater is necessary in order to protect the groundwater quality from further deterioration and save the populace from associated health risks of heavy metal contamination as well as other environmental hazards.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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