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Assessing the Impactof anthropogenic activities on groundwater quality in Maiduguri, Nigeria

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ABSTRACT

This study investigates the impact of anthropogenic activities on groundwater quality; this was achieved by determining the concentration of potential anthropogenic contaminant indicator parameters such as nitrate, chloride, phosphate, and sulphate in the groundwater samples of the study area. A total of 30groundwater samples,15 each from the northern and southern partsof Maiduguri where obtained across a period of 2 months. Results ofthe groundwater analysesshowed that nitrate (NO_3^-) has mean concentration of 13.7mg/l in the northern part (site A), and 15.53 mg/l in the southern part (site B).Chloride (Cl^-)has a mean concentration of 10.62 and 13.33 mg/l respectively in sites A and B. Sulphate (SO_4^-) has mean concentration of 3.52 mg/l in site A and 1.46 mg/l in site B. Lastly,phosphate (PO_4^-) has mean concentration of 1.39 and 1.52 mg/l in sites A and B respectively. The Mean concentrations were tested for their significant difference ($p < 0.05$) across the boreholes of the two sites.Water quality results indicate that the impact of anthropogenic activities in the study area is low to moderate currently. The outcome of this paper will be useful in planning for sustainable groundwater management strategy.

KEYWORDS: *anthropogenic activities, contamination, groundwater, Maiduguri*

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I. INTRODUCTION

Groundwater is of major societal importance for many well-known reasons. One of the most important ones is that groundwater normally offers a direct and hygienically safe source of drinking water for public, agricultural, industrial and domestic supply (Matthess, 1990). Groundwater resources, however, are becoming extremely vulnerable to a multitude of anthropogenic pollution sources (Appelo and Postma, 2005). Over the past few decades there has been an increasing focus on studies, analyses and exploration of groundwater, for the purpose of sustainable management and use. Anthropogenic activities related to incessant waste disposal, proliferation and utilisation of pit latrines, and agricultural activities can exert significant pressure on hydrogeological system on a temporal and spatial scale, primarily through the introduction of contaminants into the underlying aquifers.

Urbanisation and its resultant activities are a major factor affecting the groundwater system (Calder, 1993). Through the last century, intense human activities such asurbanisation, industrialisation, mining, agriculture, etc., have resulted in significant and clear changes in the landscape with impact on the water quality (Bronstert, 2004). Large pressure of growing pollution, increased demands for food, fodder and fuel combined with industrial activities have essentially led to rapid change in land use patterns especially in developing countries.

The United Nations projected that half of the world's population would live in urban areas at the end of 2008, and by 2050 it is predicted that 64.1% and 85.9% of the developing and developed world respectively will be urbanised (UN 2012). Consequently this demographic shift will intensify land-use activities, which will ultimately impact groundwater quality. Over the past fifty years, land use activities have dramatically changed in most parts of Nigeria and other developing nations across the world. For example, there has been a major increase in rural-urban migration and a shift from peasant farming practices to extensive agricultural system in meeting up with the demands of the booming population in urban centres.

Thus, land-use changes like this are likely to continue to into the future so long as humans continue tomeet their demands and opportunities. Therefore, collecting accurate and timely information on land use is important for assessing land use change (Giri et al., 2005) as a basis for predicting impact on water resources. It is important to note that researchers are challenged to take appropriate actions with the available limited resources in addressing existing or future problem of contamination. Also, there is therefore an urgent need for develop a feasible and practical solution that will mitigate the impact on groundwater quality caused by possible land-use change scenarios (Shaffer et al., 1996; McLay et al., 2001). The objective of this paper was to assess the impact of above ground land use related to unplanned urbanisation and agricultural activities on the underlying groundwater, as it relates to their quality. This assessment has never been carried out by previous study in the area.

Materials and methods

The study area

The study area is the capital of Borno state located between coordinates 11.8333°N and 13.1500°E in north-eastern Nigeria (Fig 1). The study area has a total land mass of 600 km^2 and lies on a vast sedimentary basin with an average elevation of 300m above sea level. The climate is semi-arid with three distinct seasons: a long hot dry season from April May. Day time temperatures are in the range 36-40°C and night time temperatures fall between 11° to 18°C. This is rainy season starts from May to September with a daily minimum temperature of 24°C and a maximum of 34°C with relative humidity of 40-65% and annual rainfall ranges from 560-600mm. The cold seasonor harmattan as it is often called runs from October to March when temperatures fall between 15° to 20°C. The vegetation of the study area is Savannah woodland which is divided into two zones: Sudan Savannah to the south and Sahel Savannah to the north.

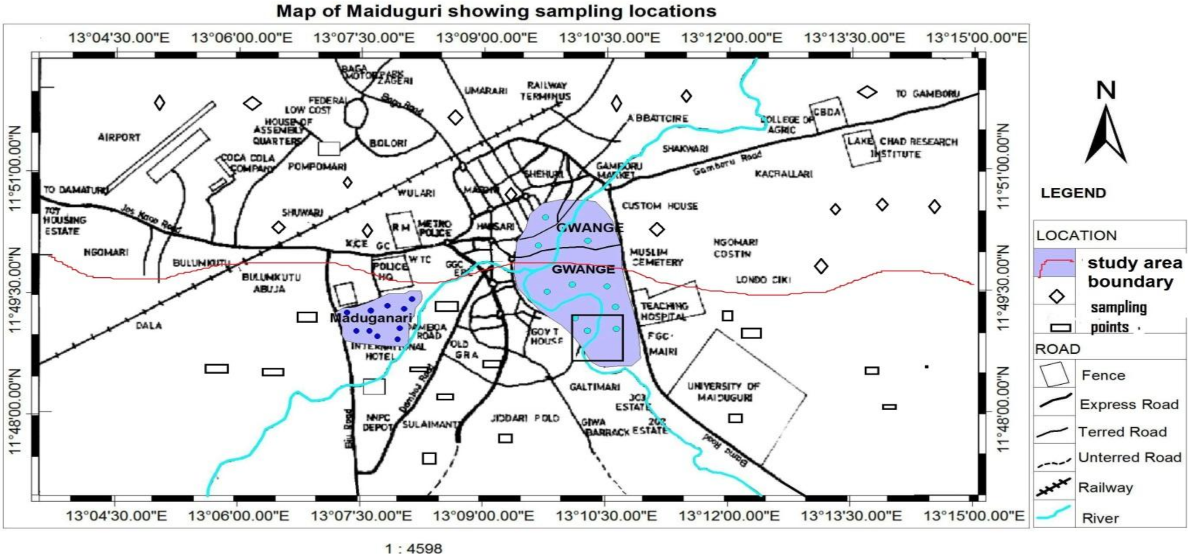

Fig.1 Map of Maiduguri showing sampling points in the northern and southern part of the city

Geology and Hydrogeology of the study area

The Cretaceous-Tertiary rift basins are filled with Lower Cretaceous to Neogene sedimentary rocks, ranging in thickness from about 3,000 meters (m) to more than 12,000 m that were deposited in fluvial, lacustrine, and marine environments (Genik, 1992; Genik, 1993). During the Early Cretaceous fluvial and lacustrine rocks were deposited in the rift basins of the Chad Basin. In the Late Cretaceous (Cenomanian to Maastrichtian) there was a marine transgression resulting from a regional sag event that formed a broad basin in which shallow marine to marginal marine and coastal plain rocks accumulated. During the Late Cretaceous to Oligocene, the last rifting phase occurred in the Chad Basin and thick fluvial and lacustrine rocks were deposited.

The Chad formation dips gently east and northeast towards Lake Chad in conformity with the slope of the land surface. Except for a belt of alluvial deposits around the edge of the basin, the formation is of lacustrine origin and consists of thick beds of clay intercalated with irregular beds of sand, silt, and sandy clay (Miller et al. 1968). From their previous investigation, Barber and Jones (1960) divided the Chad Formation into three water bearing zones designated upper, middle, and lower aquifers (Miller et al. 1968; Odada et al. 2006, Adelana 2006).

The upper aquifer is a Quaternary alluvial fans and deltaic sediments of Lake Margin origin. The reservoir in this system is composed of interbedded sands, clays, silts and discontinuous sandy clay lenses which give aquifer characteristics ranging from unconfined, through semi-confined to confined types (Maduabuchi et al., 2006). It extends from the surface to an average depth of 60 m but locally to 180m. The transmissivity of this aquifer system ranges from 0.6 to 8.3 m2/day and the aquifer yield in Maiduguri is between 2.5 to 30 l/s (Akujieze et al. 2003). This aquifer is mainly used for domestic water supply (hand dug wells and shallow wells), vegetable growing and livestock watering (Maduabuchi 2006).

In Maiduguri, the likely sources of contaminants that may pose significant treat to groundwater quality range from pit latrines, municipal solid waste disposed in open dump sites, agricultural and industrial wastes. The pathways by which contaminants travel from the source includes spaces, poorly developed or abandoned wells, and fractures in the unconsolidated geologic material of the Chad Basin through which it flows into the aquifer and the receptors are the environment, people and animals drinking water from the aquifer.

Methods

The sources of data used were based on map and non-map data. The map data used was the topographic (Maiduguri NW sheets number 90) and land use map covering the city and its environs. Based on this map, the city was divided into 2 areas; the northern and southern parts as sites A and B respectively. The non-map data involves the collection of a total of 30 groundwater samples from shallow tubewells in Northern part of the city (site A) and Southern part of the city (site B) (15 each) were randomly selected for groundwater sample collection as described by Eckhardt and USGS (2008). The major land use and anthropogenic activities in these areas include; informal settlements due to urban growth, open waste disposal, agricultural activities up stream of both sites, and human and vehicular traffic with their resultant effects. These two areas were selected, due to their high volume of anthropogenic activities; they fall within the same hydrogeological environment. They were also selected because of their population density similarities (200 inhabitants/km), and the high utilisation of pit latrines (on average 10 and 15 users per pit latrine respectively) whose contents are retained within the environment of these areas.

The selected boreholes/wells for site A were tagged BA1-15, while for site B is BB1-15. All the boreholes tap their water from the upper unconfined aquifer system of the Chad Basin; they are primarily used as the major water supply source (private) in both areas.

Samples were collected from January through February 2014. The water samples were analysed for 4 anthropogenic indicator parameters. Field parameters such as pH, EC, TDS and temperature were measured in the field using the potable HANNA pH meter (Model HI 98129). The water samples were analysed by spectrophotometry for NO^-_3, Cl^-, SO^-_4, and PO_4 were also analysed in determining the quality of groundwater in both sites using spectrophotometer (Model, 2010, USA), atomic absorption spectrophotometer (AAS) (PYE UNICAM SP-9) and titrimetric method according to APHA (1998).

Statistical analysis

Significant difference between concentration of waters in the tubewells of sites A (BA 1-15), and B (BB 1-15) respectively were tested using analysis of variance (ANOVA) using Tukey method in Minitab™16 statistical software (MINITAB©, USA). Concentration of the anthropogenic indicator parameters were tested for their significant different ($p < 0.05$) across the boreholes, based on grouping information of Tukey method at 95% simultaneous confidence interval.

Results and Discussions

The results in Tables 1 and 2 show the concentration of anthropogenic indicator parameters for site A and site Bareas, respectively. Preference was given to chloride, sulphate, phosphate, and nitrate, because their concentration in the groundwater will suggests the influence of above ground anthropogenic activities. The result in Tables 1 and 2 shows the concentration of nitrate across the boreholes of sites A and B. In site A, nitrate is having varied concentration which ranged from 28. mg/l in BA8 to 4.6 mg/l in BA13 as shown in Fig. 2 (a) and (b). Similarly in site B, nitrate recorded highest and lowest concentrations of 25.2 and 2.4 mg/l in BB7 and BB12 respectively. In both sites, the concentration of nitrate varied across the boreholes ($p<0.05$). The source of nitrate in the study area can be linked to the prevalence of pointand non-point sources of pollution such as the extensiveproliferation of pit latrines, excessive utilisation of open dumpsites, and the small to medium-scaleagricultural activities and animal husbandry as well as excessive domestic wastewaters emanating from the cluster of informal residents. Nolan et al. (2002), Squillace et al. (2002), Singleton et al. (2005) and Bakari (2014) estimate that nitrate concentration in the range of 13 to 18 mg/l are considered to indicate anthropogenic input. Therefore, the average concentrations as reported in this study (13.7 and15.53 mg/l) for sites A and B respectively fall within this bracket, and the fall far below the tolerable limit set aside by WHO (1993).

Thedifference in concentration of nitrate as in the two sites can be attributed to the difference in the two areas, where the amount of anthropogenic activity is higher in the southern part of the city due the high density of population and commercial activities. Elevated concentration (> 50 mg/L) of nitrate in waters is an indication that the waters are at the risk of pollution (Samatya et al., 2006). The levels of nitrate in waters are of particular importance for use in drinking water. Studies have shown that high nitrate in water can lead to blue baby syndrome or infantile methemoglobinaemia (WHO, 1984;1993), urinary tract diseases (Fewtrell et al. 2004). Furthermore, Bowman (1994) suggests that increased concentration of nitrate often cause blood disorders. Also, Adelana et al (2003) have suggested that chronic exposure to high levels of nitrate in drinking water may have adverse effects on the cardiovascular system.

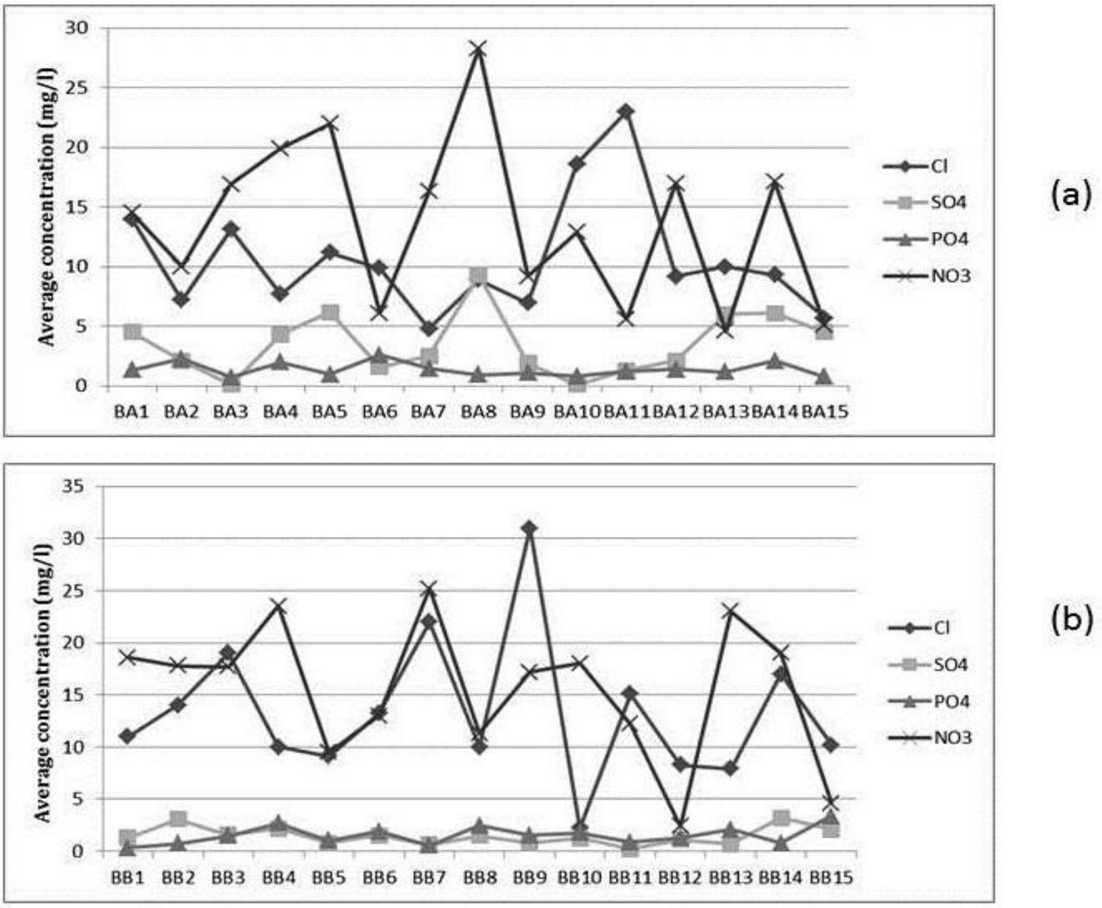

Fig. 2 (a) and (b)concentration of anthropogenic indicator parameters for sites A and B

Similarly, in site A, chloride recorded highest concentration of 23 mg/l in BA11 and lowest of 4.8 mg/ in BA7. In site B, highest and lowest concentrations for Cl were recorded in BB7 (22 mg/l) and BB10 (2.2 mg/l) thereby making the concentration of the samples to be significantly different ($p<0.05$) across the two sites. Chloride ions might be introduced to ground water from the widespread domestic sewage and waste water flowing uncontrollably in gutters of the informal settlements of the two areas or as atmospheric inputs from rainfall recharge. The latter assumption was validated by a previous study carried out by Edmunds et al. (1999), where they measured chloride concentration of 2.1 mg/l in the present day rainfall of the area. Also, Edmunds and Street-Perrott (1996) and Gaye and Edmunds (1996) have analysed the rainfall chemistry in this region and estimated concentration of chloride as 1.28 and 0.61 mg/l for dry and wet seasons, respectively. Therefore, taking these analyses into consideration, it is very likely that significant amounts of chloride were derived from agricultural activities in the adjacent farm lands and atmospheric input in the study area. The moderate level of chloride in all the samples of sites A and B suggests that anthropogenic input from sewage is moderate. Mean concentration of chloride for both sites fall below the WHO permissible limit of 250 mg/l.Water with chloride

Table 1 Results of anthropogenic indicator parameters in site A

	BA1	BA2	BA3	BA4	BA5	BA6	BA7	BA8	BA9	BA10	BA11	BA12	BA13	BA14	BA15
Cl	14±1.47	7.2±0.45	13.12±0.07	7.7±0.47	11.2±0.15	9.9±0.59	4.8±0.56	8.9±0.06	6.95±0.16	18.6±1.03	23±0.04	9.2±0.09	10±0.03	9.3±0.06	5.7±0.05
SO4	4.51±0.04	2.12±0.02	0.14±0.02	4.32±0.49	6.2±0.04	1.6±0.53	2.53±0.06	9.3±0.06	1.91±0.09	0.14±0.04	1.3±0.03	2.1±0.04	6±0.05	6.1±0.04	4.5±0.05
PO4	1.36±0.02	2.29±0.02	0.72±0.01	1.98±0.15	0.98±0.02	2.6±0.56	1.48±0.03	0.94±0.01	1.1±0.02	0.82±0.02	1.22±0.02	1.4±0.01	1.20±0.16	2.1±0.03	0.77±0.04
NO3	14.5±0.84	10±0.14	16.9±0.13	19.9±0.06	22±0.11	6.11±0.76	16.3±0.24	28.3±0.89	9.2±0.30	12.9±0.02	5.6±0.05	17±0.05	4.6±0.05	17.1±0.04	5.1±0.07

Results are mean of triplicate±STD.

Table 2 Results of anthropogenic indicator parameters in site B

	BB1	BB2	BB3	BB4	BB5	BB6	BB7	BB8	BB9	BB10	BB11	BB12	BB13	BB14	BB15
Cl	11±0.05	14±0.10	19±1.00	10±0.05	9.1±0.05	13.2±0.05	22±0.06	10±0.20	31±1.00	2.2±0.06	15.1±0.17	8.3±1.02	7.9±1.00	17±1.00	10.2±0.03
SO4	1.3±0.05	3.07±0.00	1.58±0.03	2.17±0.05	0.8±0.06	1.5±0.10	0.64±0.06	1.47±0.04	0.77±0.10	1.25±0.00	0.24±0.05	1.1±0.10	0.7±0.00	3.2±0.00	2.1±0.05
PO4	0.32±0.00	0.73±0.00	1.46±0.02	2.67±0.05	0.99±0.06	1.89±0.00	0.54±0.06	2.45±0.01	1.54±0.00	1.77±0.01	0.88±0.00	1.3±0.04	2.1±0.06	0.78±0.00	3.4±0.05
NO3	18.6±0.10	17.8±0.70	17.7±0.35	23.5±0.05	9.5±0.06	13±0.06	25.2±0.35	11.3±0.30	17.2±0.20	18±1.00	12.2±0.05	2.4±0.00	23±0.10	19±0.05	4.6±0.05

Results are mean of triplicate±STD.

In excess of drinking water standardcan be used for irrigation and some types of livestock can drink water that has chloride concentrations as high as 4,000 mg/l (NRC, 2005).

Also, in site A of the study area, sulphate has highest and lowest concentration of 6.2 mg/l in BA5 and 0.14 mg/l in BA3 and BA10 respectively as shown in Fig. 2 (a) and (b), similarly in site B, sulphate has highest mean concentration of 3.2 mg/l in BB14, and BB5 has the lowest sulphate concentration of 0.8 mg/l. Sulphate occurs naturally in geological materials, in igneous rocks, sulphur occurs mostly as metallic sulphides, and is fairly distributed in the various rock types. In arid sedimentary basins, the highest abundance is in gypsum and anhydrite (Helvoort et al., 2009). The main anthropogenic sources of sulphate in groundwater of the study area can be attributed to application of agrochemicals, the mining of gypsum in the western part of the Basin and contemporary acid rain (Quevauviller et al., 2009). However, in the study area, Goni et al. (2001) have analysed the rainfall geochemistry of the region, and posits that sulphate in the region is derived from atmospheric mixing of aerosols, and from ash of burnt forests.

Lastly,phosphorous recorded highest concentration of 2.6 mg/l in BA6 of site A and lowest concentration of 0.72 mg/l in BA3. Also in the site B, phosphorus has highest concentration of 3.4 mg/l in BB15 and lowest of 0.32 mg/l in BB1 respectively. Thus, the concentration of phosphorous varied across the boreholes and their concentrations are significantly different ($p<0.05$). The low levels of sulphate in both sites could be as a result of the removal of sulphate from the water by bacteria (Freeze and Cherry, 1979; Domagalski, 2012). The presumed anthropogenic sources of phosphate in the study area include human sewage, agricultural run-off from farm lands, sewage from animal feedlots, and the routine use of non-biodegradable detergents (Bakari, 2014). Also, higher concentration of phosphorus in receiving waters bodies especially surface water, can lead to eutrophication, which in turn, will lead to depletion of oxygen which may have effect on aquatic fauna and flora (Wolfe and Patz, 2002).

CONCLUSION

The study has assessed the impact of above ground land use activities and their associated anthropogenic activities on the shallow groundwater system of Maiduguri. It has concludedthat the anthropogenic activities such as the ever increasing utilisation of pit latrines, incessant domestic and municipal waste disposal, agricultural and industrial activities are the potential sources of anthropogenic indicator parameters as outlined, and they arelikelyto impact the groundwater resources of the area in the future if the activities are not controlled in a sustainable manner. However, their impact is currently not significant, but controlled can be a future problem.

REFERENCES

[1]. A Bakari, Hydrochemical assessment of groundwater quality of the chad basin around Maiduguri, Nigeria, *Journal of geology and mining research,6(1), 2014, 1-12.*

[2]. A Bronstert, The impact of groundwater–surface water interactions on the water balance of a mesoscale lowland river catchment in northeastern Germany.*Hydrological Processes* 21(2) 2007, 169-184.

[3]. AH Wolfe, J.A. Patz, Reactive nitrogen and human health: Acute and long term implications. Ambio: *J Human Environ. 23*(2), 2002, 120-125.

[4]. APHA, Standards Methods for the Examination of water and wastewater (20th Ed.). Washington, DC: *Am. Public Health Assoc.*, 1998

[5]. BT Nolan, K.J. Hitt, and B.C.Ruddy, Probability of nitrate contamination of recently recharged groundwater in the conterminous United States.*Environ. Sci. Technol. 36*, 2002, 2138-2145.

[6]. C Bowman, "Medical geology: new relevance in the earth sciences." *Episodes* 26(4), 2003, 270-278.

[7]. CGiri, Z. Zhu, and B.Reed, A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets. *Remote Sens. Environ. 94*,2005, 123–132.

[8]. C Maduabuchi, S. Faye, andP.Maloszewski, Isotope evidence of palaeorechargeand palaeoclimate in the deep confined aquifers of the Chad Basin, NE Nigeria.*Science of the Total Environment* 370, 2006, 467–479.

[9]. CAJAppelo, and D. Postma, Geochemistry, Groundwater and Pollution. Rotterdam: Balkema, 1993.

[10]. CB Gaye, W.M. Edmunds, Intercomparison between physical, geochemical and isotopic methods for estimating groundwater recharge in north-western Senegal. *Environ. Geol. 27*, 1996, 246-251.

[11]. CDAMcLay, et al. "Predicting groundwater nitrate concentrations in a region of mixed agricultural land use: a comparison of three approaches."*Environmental Pollution* 115(2), 2001, 191-204.

[12]. CN Akujieze, S.J. Coker, G.E. Oteze, Groundwater in Nigeria- a millennium experience-distribution, practise, problems and solutions. *Hydrogeology 11*(2), 2003, 259-274.

[13]. DA Eckhardt, Ground-water quality in western New York, 2006: U.S. Geological Survey Open-File Report 2008-1140, 36.

[14]. EO, Odada, L. Oyebande, and J. Oguntola, Lake Chad, Experience and lessons learned brief, 2006, 1-18.

[15]. GMathess, Die Beschaffenheit Des GrundWassers, Band 2, 1990

[16]. GJGenik, Regional framework, structural and petroleum aspects of rift basins in Niger, Chad and the Central African Republic (C.A.R.): *Tectonophysics, 213(1)*, 1992, 169–185.

[17]. IB Goni, E. Fellman, W.M. Edmunds, Rainfall geochemistry in the Sahel region of northern Nigeria.*Atmos. Environ.* 35(25), 2001, 4331-4339.

[18]. IR Calder, R.L. Hall, and K.T. Prasanna, Hydrological impact of eucalyptus plantation in India.*Journal of Hydrology 150*: 1993, 635–648

[19]. JLDomagalski, H. Johnson, Phosphorus and Groundwater: Establishing links between agricultural use and tansport to streams: *U.S. Geological Survey Fact Sheet* 2012-300, 4-5.

[20]. LJFewtrell, A, Prüss, P. Landrigan, and J.L. Ayuso-Mateos.Estimating the global burden of disease from environmental lead exposure. *Environ Res. 94(2)*, 2004, 120–133.

[21]. MJ Singleton, K. Woods, M.E. Conrad, D.J. Depaolo, and P.E. Dresel, Tracking sources of unsaturated zone and groundwater nitrate contamination using nitrogen and oxygen stable isotopes at the Hanford site, Washington. *Environ. Sci. Technol. 39*(1) 2005, 3563-3570.

[22]. National Research Council Mineral tolerance of animals. 2nd ed. National Academy Press: Washington, DC. 2005

[23]. PQuevauviller, P. Balabanis, C. Fragakis, M. Weydert, M. Oliver, A. Kaschl, G. Arnold, A. Kroll, L. Galbiatti, J.M. Zldivar, and G. Bidoglio, Science-policy integration needs in support of the implementation of the EU Water-Framework Directive. Environ Sci Policy 8, 2005, 203–211

[24]. PJ Squillace, J.C. Scott, M.J. Moran, B.T. Nolan, and D.W. Kolpin, VOCs, pesticides, nitrate, and their mixtures in groundwater used for drinking water in the United States. *Environ. Sci. Technol. 36*(1), 2002, 923-1930

[25]. RA Freeze, J.A.Cherry, Groundwater. 2nd edn.Prentice Hall, Eaglewood, Cliff, New Jersey, USA, 1979, 604.

[26]. RE Miller, R.H. Johnston, J. Olowu, and.UUzoma, Groundwater hydrology of the Chad Basin in Borno and Dikwa Emirates, with special emphasis on the flow life of the artesian system. *USGS Water Supply Paper 1757*, 1968

[27]. S Samatya, et al. "Removal of nitrate from aqueous solution by nitrate selective ion exchange resins." *reactive and functional polymers* 66.11, 2006, 1206-1214.

[28]. SSamatya, N.Kabay, Ü.Yüksel, M., Arda, and M. Yüksel, Removal of nitrate from aqueous solution by nitrate selective ion exchange resins. *reactive and functional polymers*, *66*(11), 2006, 1206-1214.

[29]. SM Adelana, P.I. Olasehinde, and P. Vrbka, Isotope and geochemical characterization of surface and subsurface waters in the semi-arid Sokoto Basin, Nigeria.*Afr. J. Sci. Tech. 4*(2), 2003, 80-89.

[30]. SM Shaffer, D.G. Williams, and D.C. Goodrich, transpiration estimation from of cottonwood/forest flux, *Agricultural and forest meteorology*, 105, 1996, 257–270.

[31]. SMA Adelana, P.I. Olasehinde, and, P. Vrbka, A quantitative estimation of groundwater recharge in parts of Sokoto Basin, Nigeria, International Journal Environmental Hydrology, 4(5), 2006, 1-17, ISSN 1058-3912.

[32]. vanHelvoort, J. Pieter, G. Jasper, and W.M. Edmunds. "Occurrence and behavior of main inorganic pollutants in European groundwater."*Groundwater Monitoring.Wiley, Chichester,* 2009: 83-109.

[33]. WBarber, and D.G.Jones, the Geology and Hydrogeology of Maiduguri, Borno Province.*Records of the Geological Survey of Nigeria,* 1960, 5-20.

[34]. WM Edmunds, E. Fellman, I.B. Goni, Lakes, groundwater and palaeohydrology in the Sahel of NE Nigeria: Evidence from hydrogeochemistry. *J. Geol. Soc.* 156(2), 1999, 345-355.

[35]. World Health Organisation Guidelines for Drinking Water Quality (2nd Ed.). Vol. 1: Recommendations. Geneva: *World Health Organisation*, 1993, ISBN 94-4-154503.

[36]. World Health Organisation, Guidelines for drinking-water quality, health criteria and other supporting information. *World Health Organization*, Geneva. 1984