THE QUALITY OF GROUNDWATER IN LAGOS: CASE STUDIES OF AKOKA AND BARIGA AREAS OF LAGOS STATE, NIGERIA

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Abstract: Residents of flood infested areas face security threats, not only due to damages on properties, risks of collapse buildings or physical drowning but also from water stress which could be a more damaging and slow killer. Most people depend on groundwater for their source of drinking water. As a result of floods groundwater wells can become highly polluted and stressed due to the draining of pollutants from various sources. Poor water quality spreads disease, causes death and hampers socio-economic progress, especially in densely populated areas. Monitoring of water quality in flood infested heavily populated areas such as Akoka and Bariga is therefore a good security measure towards protecting and saving of lives. In this study eight tap and two well water samples were collected for the determination of the physico-chemical and chemical parameters as well as heavy metals. Heavy metal digestion was carried out using concentrated nitric acid. The samples were analysed for lead, iron, chromium, cadmium, zinc, nickel and arsenic using atomic absorption spectrophotometer (AAS). The results showed that seven tap and one well water samples had low pH values ranging from 3.89 to 4.78, one tap water sample had pH 5.14, and one well water had pH of 7.23 but with high turbidity of 23.40NTU (above recommended value of 10). Hardness values (430 and 455 mg/L) in two tap water samples and one well water (380) exceeded the WHO recommended value (100). Some heavy metals were also higher than safe limits. For instance, only one sample was low in iron 0.12 mL; while seven samples ranged from 4.08 to 11.88 mg/L, highly exceeding WHO safe limits of 0.3 mg/L. Lead concentration (0.049 mg/L) in one location also exceeded the WHO limit of 0.01 mg/L. Chemical parameters like chloride, nitrate and phosphate also exceeded recommended levels.

Keywords: Flood, water stress, physic-chemical parameters, heavy metals, security threat

Introduction

Ground water includes all water found under the earth's surface either flowing slowly or underground lakes or pond. Ground water is mostly used for drinking purpose (Olumuyiwa *et al*., 2012). Ground water are generally known to contain dissolved minerals from the soil layer that is it is higher in mineral content than surface water because of its exposure to rocks. It has low levels of micro-organism as the soil that covers it acts as a filter to prevent most of the micro-organisms. The quality of groundwater depends on the composition of the recharge water, the interactions between the water and the soil, soil-gas and rocks with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer. Therefore, considerable variation can be found, even in the same general area, especially where rocks of different compositions and solubility occur (Bartram & Balance, 1996). Groundwater is used for a variety of purposes, including irrigation, drinking, mining and manufacturing.

The study area, Akoka and Bariga community of Lagos is located within few kilometers from Lagos lagoon which drains the whole of Lagos and also serves as a final dumping ground for wastes by ignorant common citizens. This area is constantly infested by flood as a result of its closeness to the lagoon, sometimes even during dry seasons. This area is densely populated, and diverse activities ranging from domestic to commercial activities take place on daily bases.

Most people around the world depend on ground water for their source of drinking water as it constitutes about two thirds of the fresh water reserve of the world. So also are the residents of this area dependent on ground water as their source of water for drinking and domestic purpose.

Water pollution comes from many sources including pesticides and fertilizers that wash away from farms, untreated human wastewater, and industrial waste. Even groundwater is not safe from pollution, as many pollutants can leach into underground aquifers. Some effects are immediate, as when harmful bacteria from human waste contaminate water and make it unfit to drink or swim in. In other instances such as toxic substances from industrial processes, it may take years to build up in the environment and food chain before their effects are fully recognized (WWF, 2013). Flood can lead to pollution of ground water wells due to draining of pollutants from various sources (Jamie *et al*., 1996). These pollutants can lead to the degradation of drinking water quality. Water stress could result due to climate change, such as altered weather patterns including droughts or floods, increased pollution, and increased human demand and overuse of water (WWF, 2013).

According to the United Nations estimate, more than one in every six people in the world is water stressed, meaning that they do not have access to potable water. Those that are water stressed make up 1.1 billion people in the world and are living in developing countries (UNDP, 2006). Increased pollution could result in waterborne diseases caused by lack of sanitation and hygiene are one of the leading causes of death worldwide. For children under age five, waterborne diseases are a leading cause of death. According to the World Bank, 88 percent of all waterborne diseases are caused by unsafe drinking water, inadequate sanitation and poor hygiene (CNN, 2007). The environmental conditions of drinking water sources in some parts of Lagos, especially in flood infested areas of the State are not good enough (Plate 1). Worse cases exist within our communities.

Plate 1: A drinking water tap beside a canal in a residential are

In assessing ground water quality, it is important to determine the characteristics or parameters of the water. Parameters can be physical, chemical or biological in nature. Physical parameters of water include but not limited to temperature, dissolved oxygen and suspended solids. Chemical parameters are a measure of substances, such as nutrients, heavy metals and pesticides, which are dissolved in the water or are in particulate form. Biological parameters refer to aspects of the living environment, from microscopic algae and invertebrates to macrophytess. The followings are the physicochemical parameters that can be determined in water: temperature, pH, colour and taste, odour, dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, total dissolved solids (TDS) and turbidity.

According to WHO organization, about 80% of all the diseases in human beings are caused by water. Once the groundwater is contaminated, its quality cannot be restored back easily and to device ways and means to protect it. To communicate information on the quality of water to the concerned citizens and policy makers, analysis of water is utmost important. It, thus, becomes an important factor for the assessment and management of groundwater (Shivasharanappa *et al*., 2012).

The objective of this study is to assess the quality of water and the security threats posed by water stress on flood infested areas of Akoka and Bariga in Lagos, Nigeria.

Materials and Methods

Sample collection

Water samples were collected in 250 ml glass bottle for dissolved oxygen (DO) and biochemical oxygen demand (BOD), 1ml alkali-iodide-azide solution was added to each water sample in the DO bottles, with 1 ml Manganese (II) sulphate immediately after collection and corked. This helped to preserve the dissolved oxygen present in the water at the point of collection. Samples were collected in plastic bottles for the physiochemical parameters, pre-cleaned by washing with non-ionic detergents, rinsed in tap water. Before sampling, the bottles were rinsed three times with sample water before being filled with the samples (Plate 1 & 2).

Plate 2: Water samples from ten locations for analysis in the Chemistry laboratory of the University of Lagos (from left are samples B, E, G, C, H, I, J, D, A and F)

Two well water and eight borehole water samples were collected from houses in the study area. One of the bore hole water samples was collected inside the kitchen of one of the houses. Six borehole water samples were collected from the street taps, while one borehole water sample was collected from a tap within a residential compound. A total of ten samples were collected. The samples are labelled A to J as shown in the Table 1.

Table 1: Sample location and description

Sample location	Description of sample location	Sample source
A	33 Afolabi Brown (kitchen)	Bore hole
B	33 Afolabi Brown (compound)	Bore hole
C	28 Afolabi Brown street	Bore hole
D	60 Oshifolarin street	Bore hole
E	24 Ogunleye street	Open well
F	8 Ogunleye street	Bore hole
G	7 Ifeanyi street	Bore hole
H	12 Oshifolarin street	Bore hole
I	11 Olawale Lawal street	Bore hole
J	11 Oshifolarin street	Open well

Sample analysis

All field meters and equipment were checked and calibrated according to the manufacturer's specification. Temperature readings were taken while on site. Sample analysis for the physico-chemical, chemical and heavy metals were carried out according to Alani *et al*. (2014).

pH: The pH readings were taken in the laboratory. The pH meter was calibrated with the following buffer solutions of pH 4.0, 7.0 and 10.0, respectively at room temperature. The probe of the pH meter was thoroughly washed with distilled water and then each sample at every reading. The pH of the samples was measured by dipping the probe into the sample without stirring according to APHA (1998).

Turbidity (FTU): The turbidity of each water sample was measured using HACH DR 2000 direct reading spectrophotometer method 8237. The turbidity of the sample was estimated against deionized water as a blank at a wavelength of 450 nm.

Total solids (TS): The total solid was determined gravimetrically by taking aliquot of each water sample in a clean, dry beaker. He water was then evaporated on a hot plate until all the water was almost dry. The drying process was completed in an oven whose temperature was set at 150˚C. The difference in mass of empty beaker and the beaker containing the solids was computed.

Dissolved oxygen (DO): The DO of each water sample was determined using a portable Orion 3. DO meter. The DO meter was calibrated with water saturated with air after which the different water samples were tested in turn.

Biological oxygen demand (BOD520): The BOD was determined using the Winkler method. The method involves estimating the dissolved oxygen content of the water sample at zero day (day of sampling) and then, the fifth day of five days of incubation at 20˚C in the dark against a blank.

Chloride was determined by titrimetric method.

Phosphate (PO4 3- P): The phosphate was determined using the HACH DR 2000 direct reading spectrophotometer method 8048. The HACH phosver 3, phosphate powder pillow reagent was used in 25 ml of the water sample against deionized water as blank at a wavelength of 890 nm.

Sample preparation and analysis for metals

Each of the five water samples was thoroughly shaken together. Then, 100 ml of each was transferred into a beaker and 5 ml of concentrated nitric acid was added. The beaker was placed on a hot plate and evaporated to dryness. It was then cooled and another 5ml concentrated nitric acid was added. Heating was continued until a light-coloured residue was observed. Then 1 ml concentrated nitric acid was added and the beaker was warmed slightly to dissolve the residue. The walls of the beaker were then washed with distilled water. The extract was filtered and cadmium, iron, copper, manganese, lead, chromium, cobalt, nickel and zinc were determined in the filtrates using the Atomic Absorption Spectrophotometer. About 5 g of each of the five air-dried, sediment samples, passed through a 2 mm sieve, was digested with 10 ml nitric acid in a standard conical flask until the brown fumes disappeared. Each was cooled and distilled water added to make up to 50 ml in the standard conical flask. The extract was filtered and cadmium, iron, copper, manganese, lead, chromium, cobalt, nickel and zinc were determined in the filtrates using the Atomic Absorption Spectrophotometer.

Results and Discussion

Physico-chemical parameters of the water samples

The pH: The pH values of the water samples range from 3.89 – 7.23. Nine of the water samples analysed were acidic, with pH values below safe limits for potable water (Table 2). The low values could also be as a result of natural geological conditions of the site. Acidic condition in ground water could also be due to surrounding soil and bedrock. Low pH occurs when atmospheric oxygen and water comes in contact with sulphides, such as pyrite, which react and forms acid. The acid then dissolves naturally occurring metals, resulting in acid mine drainage and elevated concentrations of metals in water (Kitt, 2000). Flooding at the study area occurs almost all year round. According to UNESCO/WHO/UNEP (1996), the most serious consequences of acidification of groundwater are the increased mobilisation of trace elements, especially aluminium, in soils and aquifers, and the increased solubility of some metals in water distribution systems, both resulting from the lowering of the pH. The constant flooding of the study area could enhance these, thus resulting in the low pH of the ground water.

Table 2: Physico-chemical parameters of water samples

Sample location	pH	Turbidity	TDS	Hardness	DO	BOD	Temperature	Taste
A	**4.01**	1.4	44	**455**	**4**	**8**	27.4	Salty
B	**3.89**	3.28	41	**430**	**4**	**6**	27.3	Salty
C	**4.48**	1.55	10	75	**3.6**	4	27.3	-
D	**4.58**	4.11	6	20	**2.8**	2	27.5	-
E	7.23	**23.4**	65	**380**	**2.8**	2	27.4	-
F	**5.14**	3.05	3	35	**3.2**	4	27.3	-
G	**5.14**	4.16	9	35	**4**	**6**	27.5	-
H	**4.46**	3.07	20	50	**2.8**	2	27.2	-
I	**5.14**	2.95	3	10	**3.6**	5	27.5	-
J	**4.14**	2.58	11	**100**	5.2	**12**	27.5	-
Indian standard	6.5-8.5	10	500	300	-	30	-	-
WHO	-	-	1000	100	5	6	-	-
EPA	-	-	-	200	-	5	-	-

This acidity could lead to leaching of metals from pipes, and fixtures, such as copper, lead and zinc. It could also lead to damage of metal pipes which can cause aesthetic problems, such as metallic or sour taste, laundry staining or blue-green stains in sinks and drains. It can be observed that the low pH values contribute greatly to water stress in these flood infested area. This is reflected in the high load of heavy metals in almost all the samples analysed. Acidic water is soft and corrosive. The flood then enhances the leaching of the corroded heavy metals into the ground water which is a major source of drinking water to the community in question. Most of the residents buy water for all domestic uses, including washing of cloths. In our findings, we discovered that the residents of a particular compound on 33 Afolabi Brown Street have only been using their water for flushing of toilet for years now. Reason for this is reflected in the physic-chemical properties of the water as seen on table 2. In this location, pH values in the kitchen tap and the compound tap were 4.01 and 3.89 respectively at the time of study. The acidity could actually be tasted in the water. This is very true as personal interviews with the residents revealed that they buy water for all other purposes, except flushing toilet, throughout their stay in that resident. The condition described here demonstrates a high level of water stress, which is a condition that occurs when the demand for water exceeds the available amount of fresh water during a certain period or when poor quality restricts its use. The more sensitive a species, the more affected it is by changes in pH. In addition to biological effects, extreme pH levels usually increase the solubility of elements and compounds, making toxic chemicals more "mobile" and increasing the risk of absorption by aquatic life. Aquatic species are not the only ones affected by pH. While humans have a higher tolerance for pH levels (drinkable levels range from 4-11 with minimal gastrointestinal irritation), there are still concerns. pH values greater than 11 can cause skin and eye irritations, as does a pH below 4. A pH value below 2.5 will cause irreversible damage to skin and organ linings. Lower pH levels increase the risk of mobilized toxic metals that can be absorbed, even by humans, and levels above 8.0 cannot be effectively disinfected with chlorine, causing other indirect risks. In addition, pH levels outside of 6.5-9.5 can damage and corrode pipes and other systems, further increasing heavy metal toxicity.

Temperature: The water temperatures ranged from 27.2 to 27.5°C, almost the same at all the locations. Water temperature is a critical aspect of aquatic habitat as water temperature affects nearly all other water quality parameters. Aquatic organisms are adapted to certain temperature ranges. As the upper and lower limits of the range are approached, the organism becomes more susceptible to disease (Kitt, 2000). Temperature is a significant biological factor that plays an important role in the metabolic activities of organism. Temperature enhances the growth rate of microorganisms, some of which produce bad tasting metabolites. The odour of substance is also influenced by temperature (Olumuyiwa *et al*., 2012). The density of water varies with temperature. In an established system the water temperature controls the rate of all chemical reactions, and affects fish growth, reproduction and immunity (Patil *et al*., 2012). Temperature in this study had equal influence at all the locations and thus none of the results obtained has a different temperature influence. Water temperature is a physical property expressing how hot or cold water is. Water temperature plays a major role in the quality of aquatic life and habitats. Water temperature affects every other water parameters and can alter the physical and chemical properties of water. Water temperature can inhibit plant respiration and photosynthesis. Algae photosynthesis will increase with temperature. High water temperatures can increase the solubility and thus toxicity of certain compounds. This compound may include heavy metals such as cadmium, zinc and lead as well as ammonia. Mortality rates for zinc are significantly higher at temperature above 25°C than at temperature below 20°C. This occurs because tissue permeability, metabolic rate and oxygen consumption all increase with increased temperature (Hayashi, 2004).

Taste and odour: The samples with the lowest pH values (3.89 and 4.01) are two samples from 33 Afolabi Brown and these are the only samples with very bad salty taste. This is in agreement with Olumuyiwa's work on characteristics, qualities, pollution and treatment of groundwater. He stated that pH influences the taste and odour of a substance significantly, especially when it controls the equilibrium concentration of the neutral and ionized forms of a substance in solution. He quoted that the average threshold increases from 0.075 to 0.450 mg/l as the pH increases from 5.0 to 9.0 (Olumyiwa *et al*., 2012).

Turbidity: The samples with highest turbidity of 23.4 (above safe limit), was sample E, an open well at number 24 Ogunleye street. Turbidity of water affects other water quality parameters such as colour, when it is imparted by colloidal particles. It also promotes the microbial proliferation, thus affecting negatively the microbiological quality of water. It also affects the chemical quality of drinking water through the formation of complexes between the turbidity causing humic matter and heavy metals (Olumuyiwa *et al*., 2012). Turbidity may be composed of organic and or inorganic constituents. Organic particulates may harbour microorganisms. Thus turbidity may increase the possibility for water borne disease. Turbidity- induced changes that can occur in a water body may change the composition of an aquatic community. Turbidity due to large volume of suspended sediment will reduce light penetration, thereby suppressing photosynthetic activity of phytoplankton, algae, and macrophytes especially those farther from the surface. Turbidity due to large volume of organic particles can lead to dissolved oxygen depletion of the water body (Dunne and Aalto, 2013).

TDS: TDS values were low ranging from 3 to 65. The values were too low at some locations. Total dissolved solids indicate the salinity behaviour of groundwater. TDS in drinking-water originate from natural sources, sewage, urban runoff and industrial wastewater. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals. The palatability of water with a TDS level of less than 600 mg/l is generally considered to be good; drinking-water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/l. The presence of high levels of TDS may also be objectionable to consumers, owing to excessive scaling in water pipe, heaters, boilers and household appliances. No health-based guideline value for TDS has been proposed. Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste (Emmanuel *et al*., 2013).

Hardness: Hardness is the property of water which prevents the lather formation with soap and increases the boiling points of water. Hardness of water mainly depends upon the amount of calcium or magnesium salts or both (Patil and Patil, 2010). Source of hardness include sewage and run-off from soils particularly limestone formations, building materials containing calcium oxide and textile and paper materials containing magnesium. Hardness although have no health effects it can make water unsuitable for domestic and industrial use. Samples A and B (33 Afolabi Brown kitchen and compound) were the hardest with values of 455 and 430, followed by the open well at J, 24 Ogunleye Street (380), respectively. It is quite understandable why the residents at number 33 Afolabi Brown Street cannot even wash cloths with their water. Their water is highly stressed. According to some classifications, water with hardness up to 75 mg/l is classified as soft, 76 to 150 mg/l is moderately soft, 151 to 300 mg/l as hard and more than 300 mg/l as very hard (Shivasharanappa *et al*., 2012). Groundwater samples near Industrial Area, Cuddalore District, Tamilnadu, India noticed that the hardness of the studied location ranged from 158 to 536 mg/l.

DO: The level of dissolved oxygen in water is used as an indication of pollution and its portability. This thus forms a key test in water pollution control activities and waste treatment process control activities and waste treatment process control (Janardhana *et al*., 2010). The Nine of the 10 samples had low DO values (ranging from 2.8 to 4), below the WHO recommended level of 5 (WHO, 2008). Only the open well at number 11 Oshifolarin Street had the DO of 5.2. Dissolved oxygen in drinking water gives the water good taste. Depletion of dissolved oxygen in water supplies can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide. It can cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated. The findings in this study also confirmed the water stress at this study area.

BOD: The test for BOD is typically conducted over a five-day period. The greater the measure of the decomposable matter presents in water, the greater the oxygen demand and the greater the BOD value. BOD is the measure of the use of dissolved oxygen by life forms, particularly during decomposition (Suthar *et al*., 2012). The BOD levels were high in the two samples from number 33 Afolabi Brown as well as in number 7 Ifeanyi Street. It was highest in number 11 Oshifolarin open well. This also reveals pollution levels. Biochemical oxygen demand measure the amount of oxygen required or consumed for microbiological decomposition (oxidation) of organic material in water. The presence of high BOD may indicate faecal contamination or increases in particulate and dissolved organic carbon from non- human and animal source that can restrict water use and development.

Chemical parameters

Chloride and Phosphate: Five samples were very high in chloride content ranging from 283.60 – 1311.65 mg/L exceeding the WHO safe limit of 250 mg/L. Phosphate contents of all samples were very high ranging from 1.80 – 21.40 mg/L and exceeding the WHO safe limits of 0.03 mg/L. (WHO, 2003). According to Alani *et al*. (2014), phosphates contribute to turbidity in the water column with potential to suppress production of phytoplankton, macroalgae and other submerged aquatic plants. Reduced levels of dissolved oxygen in the water column can result in the release of phosphate from suspended particles and the sediment (Nixon *et al*., 1995). This was confirmed in our result in Table 2, where the DO levels of nine out of ten samples were lower than recommended levels. The phosphate levels in all the samples exceeded the WHO limits thus agreeing with Nixon *et al*. (1995).

Heavy metals

The percentage occurrence of heavy metals in the water sample was quite high as shown in Fig. 1. Chromium, iron, zinc, nickel and arsenic percentages were high. Lead was not found in many of the locations but was high in one of the locations found.

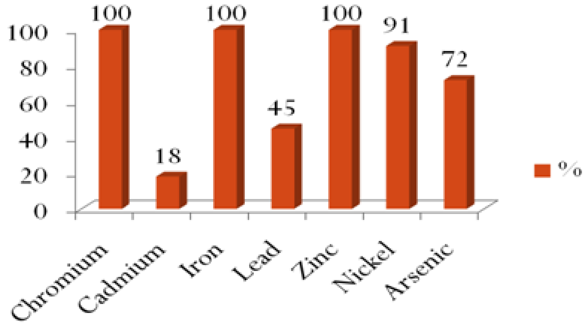

Fig. 1: Percent occurrence of heavy metals in ground water samples

Iron: Seven samples were found to have high iron concentrations ranging from 4.08 – 11.88 mg/L which are higher than WHO safe limits. A more common problem for humans is iron deficiency, which leads to anaemia. A man needs an average daily intake of 7 mg of iron and a woman 11 mg; a normal diet will generally provided all that is needed. Iron can be found in meat, whole meal products, potatoes and vegetables. The human body absorbs iron in animal products faster than iron in plant products. Iron is an essential part of hemoglobin; the red colouring agent of the blood that transports oxygen through our bodies. Iron may cause conjunctivitis, choroiditis, and retinitis if it contacts and remains in the tissues (Alani *et al*., 2014)

Chromium: Five samples were found to have chromium values exceeding WHO limits. For most people eating food that contains chromium (III) is the main route of chromium uptake. The health hazards associated with exposure to chromium are dependent on its oxidation state. Adverse effects of chromium on the skin may include ulcerations, dermatitis, and allergic skin reactions. Inhalation of hexavalent chromium compounds can result in ulceration and perforation of the mucous membranes of the nasal septum, irritation of the pharynx and larynx, asthmatic bronchitis, bronchospasms and edema. Respiratory symptoms may include coughing and wheezing, shortness of breath, and nasal itching (Alani *et al*., 2014).

Lead: One location, number 7 Ifeanyi Street, was found to have very high concentration of lead 0.049 mg/L as compared to WHO safe limit of 0.01 mg/L. Lead affects almost every organ system in the human body. The central nervous system is particularly vulnerable in infants and children under age six. The effects are the same whether it is breathed or swallowed. Large amounts of lead exposure may lead to blood anemia, severe stomachache, muscle weakness, and brain damage (Alani *et al*., 2014). Lower levels of exposure, may affect a child's mental and physical growth leading to learning disabilities and seizures.

There are potential risks of chromium associated diseases the use of tap and well water from the study area. The water stress level due to iron, chromium and lead pollution at the study area is high.

Conclusion

The findings revealed that underground water, which is the major source of drinking water in flood infested areas of Lagos is highly stressed with loads of pollutants. Safe Drinking water is a basic need for good health and it is also a basic right of humans. The security threats of water stress highlighted in this study requires immediate attention by the authorities in charge, for the safety of the citizens affected.

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Conflict of Interest
Authors declare there is no conflict of interest related to this study.

References
Alani R, Alo B & Ukoakonam F 2014. Preliminary investigation of the state of pollution of Ogun River at Kara Abattoir, Near Berger, Lagos. *Int. J. Environ. Sci. Toxic*., 2(2): 11- 23.
APHA (American Public Health Association) 1998. American Water Works Association.; Water Environment Federation. Washington, DC: APHA-AWWA-WEF, (1998). Standard methods for the examination of water and wastewater. National government publication: English : 20th ed.
CNN 2007. Cable News Network All About: Water and Health. 18 December, 2007.
Dunne T & Aalto RE 2013. Large river floodplains. In: JF Shroder (ed.) Treatise in Geomorphology, 9: 645-678, Academic Press, San Diego, 2013.
Emmanuel B & Nurudeen A 2013. Physicochemical Analysis of Groundwater Samples of Bichi Local Government Area of Kano state of Nigeria.
Hayashi M 2004. Temperature-Electrical Conductivity Relation of Water for Environmental Monitoring and Geophysical Data Inversion in Environmental Monitoring and Assessment. Netherlands. Kluwer Academic Publishers.
Bartram J & Ballance R 1996. World Health Organization & United Nations Environment Programme. Water quality monitoring : a practical guide to the design and implementation of freshwater quality studies and monitoring programs / edited by Jamie Bartram and Richard Ballance. London: E & FN Spon. https://apps.who.int/iris/handle/10665/41851
Janardhana RD, Hari B, Swami A & Sumithra S 2010. Physicochemical Characteristics of Groundwater of Vuyyuru, Part of East Coast of India.
Kitt FP 2000. Water Quality and Monitoring. Master Watershed Steward, Connecticut Department of Environmental Protection, pp. 1- 18.
Nixon SC, Gunby A, Ashley SJ, Lewis S & Naismith I 1995. Development and testing of General Quality Assessment schemes: Dissolved oxygen and ammonia in estuaries. Environment Agency RandD Project Record PR 469/15/HO
Olumuyiwa IO, Fred AO & George MO 2012. Groundwater: Characteristics, Qualities, Pollutions and Treatments.
Patil PN, Sawant DV & Deshmukh RN 2012 Physicochemical Parameters for Testing of Water (India).
Patil VT & Patil RR 2010. Physicochemical analysis of selected groundwater samples of Amalner Town in Jalgaon District, Maharashra, India. *E. J. Chem.*, 7(1): 111-116.
Shivasharanappa D, Padaki Srinivas, Mallikarjun S Huggi 2012. Study on the Physicochemical Characteristics of Ground Water Of Bidar City And Its Industrial Area.
UNESCO/WHO/UNEP 1996. Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring - Second Edition Edited by Deborah Chapman © 1992, ISBN 0 419 21590 5 (HB) 0 419 21600 6 (PB)
United Nations Development Programme 2006. Human Development Report 2006: Beyond Scarcity–Power, Poverty and the Global Water Crisis. Basingstoke, United Kingdom: Palgrave Macmillan.
World wide Fund for Nature "Water Scarcity. Threats". WWF. 2013. Retrieved 20 October 2013.
WHO (World Health Organization) 2010. Safe water and Global Health *WHO International.25 June, 2008.Retrieved 25 July 2010.*
WHO 2003. Chloride in Drinking Water. Background Document for Development, WHO Guidelines for Drinking Water Quality.
WHO 1993. Guidelines for Drinking Water Quality. 2nd Edition. World Health Organisation, Geneva, Switzerland.