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POTENTIAL IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES IN PORT HARCOURT, NIGERIA

Raphael Oaikhena Oyanyan*, Michael Akong Toko
* Geological Consultancy Unit, Notables Associates Limited, Ada George Road, Mgbuoba, Port Harcourt, Nigeria
Project Management Consultancy Unit, Port Harcourt Water Corporation, No.6 Water Works road, Rumuola, Port Harcourt, Nigeria.

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ABSTRACT
Global warming is permanently changing the climate. Hydrological cycle is being intensified with increase in the rate of evaporation, condensation and precipitation resulting in frequent intense rainfall, flooding, sea level rise and drought in different parts of the world. Groundwater is connected to the hydrological cycle. The rate of aquifer's recharge depends among others mainly on the amount of rainfall. Port Harcourt is part of the globe and not exempted from climate change; and groundwater is the main source of fresh water. Therefore, this study presents a critical evaluation of the hydrogeological/hydrological and meteorological setting of Port Harcourt aimed at predicting the potential impact of climate change on the groundwater resources. This study indicates that the groundwater resource is robust due to aquifer thickness, steady rainfall almost throughout the year and permeable overlying rock materials. However, some locations of shallow coastal aquifer are at risk of saltwater intrusion. Regional location and the geomorphology of Port Harcourt make it prone to flooding that can be exacerbated to catastrophic dimension by climate change. Low prevention capacity of overlying soils and proliferation of private boreholes inundated during flooding makes it easier for pollutants mobilized during flooding to get into the aquifer and pollute the groundwater. Therefore, Groundwater resources in Port Harcourt may be robust, but it's gradually diminishing in quality.

INTRODUCTION
Sustainable and reliable water supply is a necessary prerequisite for a flourishing civilization. It is used for industrial, municipal and personal purposes. As the saying goes "no water, no life and no human existence". Even vegetation responsible for the production of food and oxygen for animals and humans also depends on it. Freshwater is that water that contains very little or no concentration of dissolved salt such as sodium chloride (NaCl) and other dissolved solids. When it is devoid of chemical and biological contaminants, and suitable for drinking, then it is termed "potable water". Freshwater is obtained from rainfall (precipitation from atmosphere), streams, rivers or underground (below the ground surface). Water derived from underground or below the ground surface is called the groundwater. It is tapped with either mechanically drilled borehole or hand-dug well.

Groundwater is the world's largest source of freshwater (Fetter, 1988; Taylor et al. 2009). Port Harcourt city largely depends on it. Boreholes of different sizes and depth are used to tap the groundwater in almost every living house, office building and hotel. Even the industries such as petrochemicals and power depend on it for the cooling of their industrial plants. It is an obvious fact that the city of Port Harcourt is growing on a very fast rate with a corresponding increase of groundwater consumption or abstraction with submersible and surface pumps (Amadi, 2010). The rate of abstraction can make any discerning minds to sometime wonder what will happen to the city if groundwater is exhausted. By the way, can it ever be exhausted or diminished in volume and or quality?

Groundwater naturally recharged or replenished via steady rainfall. During rainfall, some water percolate into the ground by a process termed infiltration. The infiltration result in the saturation of soil and rock at some depth. The top of the saturated zone is the water table (Fetter, 1988). The overland–flow from rainfall that did not infiltrate into the ground will drain to the river, stream, or ocean. Parts of the rain-water that remain as moisture in the soil are absorbed by plants. The saturated soils also discharge water as spring or as seepage into ocean, river or lake. Water goes back to the atmosphere through evaporation from soil and water bodies, and transpiration from plant, to be precipitated back to the ground as rain to complete a cycle called "the hydrological cycle".

From the study of the hydrological cycle, one understands that the higher the rate/frequency and amount of rainfall, the higher the rate of groundwater recharge or replenishment. When the groundwater is inadequately replenished, drying-up of water boreholes or fall in water table is inevitable. Also seepages into streams or river will also reduce which affects the volume of water in the dams used for either power generation or agricultural irrigation. Climate which is defined as the average weather in terms of the mean and its variability over a certain time-span and a certain area (IPCC, 2007; Bate et al., 2008; Kumar, 2012), determines the amount and intensity of rainfall and to a large extent also determines the quantity and quality of water in the ground. This is because climatic conditions such as temperature, absolute humidity and wind determine the rate of evaporation, transpiration and condensation in the hydrological cycle.

According to Bate et al. (2008), the Inter-Governmental Panel on Climate Change (IPCC) Fourth Assessment Report 2007 reports that human activities such as the release of greenhouse gases (e.g. Co_2 and N_20) have resulted in global warming– a term used to describe a gradual increase in the average temperature of the earth's atmosphere and ocean. The scientists agreed that the average temperature of the earth has risen between 0.4 and 0.8^0c over the past 100 years. They predicted an increase of 2 to 4^0c over the next 100 years. This change in temperature is permanently changing the global climate.

According to Kumar (2012), climate change is defined as a statistically significant variation of the mean state of climate or its variability lasting for decades or longer. The global climate change includes frequent heavy rainfall and associated flood, rising sea level, drought etc. This change is different from the usual natural one that leads to dry and wet season. According to Treidel et al. (2012), changes in climate are expected to affects the hydrological cycle altering surface water levels and groundwater recharge to aquifer (rock or soil that stored and yield water) with various other associated impacts on natural ecosystem and human activities.

Port Harcourt City that largely depends on groundwater for source of fresh and potable water is part of the globe and can certainly not be exempted from the impact of global climate change. It is an undeniable fact that continuous supply of fresh water is necessary for the optimisation of her commercial and economic development. Therefore, the aim of this paper is to examine critically the potential impact of climate change on groundwater resources in Port Harcourt. It also includes the identification of the areas that may likely be most impacted in years to come.

Study Area

Port Harcourt is the capital of Rivers State, one of the oil rich states of Niger Delta in the South-South region of Nigeria of Africa (Fig.1). The oil city as popularly called is located between latitude $04^0 43^1$N- $05^0$00N and longitude $06^0 45^0$E - 07^0 06^1 E. The city is made up of two local Government areas Obio- Akpor and Port Harcourt City. The city consists of clans or communities. Among them are Rumuola, Rumuokwurushi, Mgbuoba, Choba, Trans-Amadi, Rumuokoro, Rumueme, Borokiri, Bundu, Diobu, Rumuokwuta, Rukpokwu and etc.

Regional Geology and Hydrogeology

Niger delta basin is a sag basin formed as a result of the collapse of the margin on the ocean-ward side of the lower Benue Trough due to sediment loading. It is made up of three lithostratigraphic units – Benin, Agbada and Akata Formation (Short and Stauble, 1967; Reijers, 2011). The top-most formation, Benin Formation, which can be impacted by human/industrial activities consist of continental and fluvial sands, gravel, and back swamp deposits. In the coastal areas and flood plains, the Benin Formation is overlain by the Quaternary alluvium deposits which consist of sand and gravel. Below the Benin Formation is the Agbada Formation which is a paralic to marine coastal and fluvial-marine deposits mainly consists of sandstones and shales. It has thickness that varies between 300m and 4500m (Weber and Daukoru, 1975). The bottom Formation, Akata, is a marine pro-delta megafacies, comprising at least 6500 m (21,400 ft) of marine clays with silty and sandy interbeds.

According to Adelana, et al. (2008), the most important aquifers in the Niger Delta are the Deltaic (Quaternary alluvium) and Benin Formations and they occur either as unconfined and confined. The unconfined aquifer closed to the ground surface is easily impacted by human and industrial activities. In the Deltaic Formation, the water-table in the unconfined aquifer range from 0 to 9m below ground level and it is recharged steadily through direct precipitation and by major rivers such as the river Niger and its distributaries. According to Offodile (1992), the Deltaic Plains have specific capacities in the range of 160–320m^3/d/m. While in The Benin Formation, depth to water table ranges between 3 and 15m below ground surface. It is sandy and highly permeable, with specific capacity of 150 -1400m^3/d/m. Depth to aquifers confined by shale or clay bed varies across Niger Delta. However, according to Adelana, et al. (2008), borehole data indicate a depth of approximately 100m. Specific capacity of confined aquifer in the Deltaic Formation varies from 90–320m^3/d/m, while in the area underlain by the Benin

Formation, specific capacity varies between 140 and 180m^3/d/m. The regional flow direction of ground water in Niger delta is from the Northeast to the Southwest direction.

Fig.1: Map of Nigeria showing location of Rivers state and google map of Port Harcourt showing roads, rivers and locations of some communities

Topography and Hydrology/Hydrogeology of Port Harcourt

Port Harcourt is located, is within the lowland areas of Niger delta. Geomorphologically, the area is flat to sub-horizontal as it slopes very gently seawards. But there are some areas of depressions that are fresh water swamps. The elevations range from 10 to 26m above mean sea level. The city is transverse by some creeks and rivers that trend valleys with very gentle slope and low overbanks (Fig.1). The river network conveys water and sediments through some major rivers/estuaries such as Bonny river and Imo river into the Atlantic Ocean. There is seaward sloping nature of the coastal plain strata. Aquifers are recharged in inland areas through precipitation and the water flow down-gradient and then discharged by several mechanisms such evapotranspiration, direct seepages to streams, boreholes etc.

In Port Harcourt, Boreholes normally penetrate lateritic soils before the aquifer that is made up of very porous sand with rare detrital clays and coarse downward. Most water boreholes tap water from unconfined aquifer except in a location in Woji community where a dark gray consolidated clay overly the aquifer at around 15m depth. Generally, the average water table depth ranges from 1.5m (in swampy areas) to 12m. According to Amajor (1986; 1991), the aquifers in Port Harcourt are predominantly sand beds with minor clays, lignite and conglomerate. The sands are very fine to coarse grained, sub-angular to sub-rounded, Poor to fairly well sorted and mostly lithic arenite. The aquifer thickness is up to 50m and stacking is common. Still according to Amajor (1986), the transmissivity of aquifer in Port Harcourt range from $1.05x10^2$ to $11.3x10^2$m/s, while the coefficient of storage varies between $1.07x10^4$ and $3.53x10^4$ and specific capacity values lie between 19.0 and 139.8m^3/h

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drawdown. The water is drinkable with physicochemical properties within WHO limits (Nwankwoala and Udom, 2014). High Iron and chlorides are only in localised places which include areas that tap water from shallow coastal aquifers (Ukpaka and Chinedu, 2016). With these aquifer characteristics, Port Harcourt has robust groundwater resources.

Regional Climate

Rivers state, where Port Harcourt is situated, is one of the coastal states in Nigeria dominated by humid air masses and the associated rain bearing south-westerly monsoon wind and the dry harmattan, associated with north easterly wind that reaches the states occasionally in the month of January and February (Short and Stauble, 1967). The two winds however thus give two seasons- wet and dry. The wet season spreads from April to October while the dry season is from November to March. The mean annual rainfall exceed 2000 mm and rain falls all year round with over 85% during the wet season (Iloeje, 1972). The peak of rain is usually between August and September.

MATERIALS AND METHODS

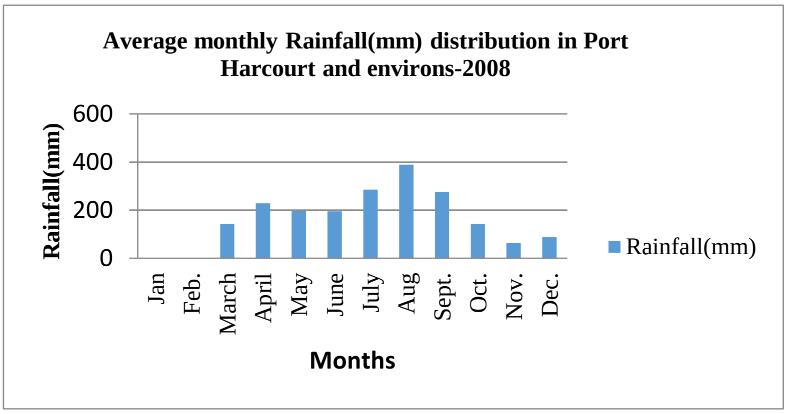
To achieve the aim of study, past works on the geology/hydrogeology of Port Harcourt were studied. Rainfall and temperature data acquired from the meteorological station of Port Harcourt International Airport were statistical analysed. Water level depth of boreholes at various locations were measured with water depth meter. Well known and experienced water borehole drillers in the town were also consulted on variations in water level and first aquifer depth in different parts of the city.

RESULTS AND DISCUSSION

Meteorological setting of Port Harcourt

Rainfall

The average monthly distribution charts (Fig. 2a and b), show significant rain is always experienced for about eight to nine months in the year in what is typically known as the rainy season in Nigeria, while dry season is experienced for four months with cold harmattan breeze in January. The wet season spreads from April to October while the dry season is from November to March. Highest rainfall values are obtained in July to September (400-800 mm) with a short break of about a week plus in the month of August called, the August Break. The months considered as dry are not even free from occasional rainfall because records up to 65 mm of rain have been obtained for such dry periods. The month considered as a month of complete no rain (0mm rainfall) can be either month of December, January or February. Figure 3 shows that the years in which the average amount of rainfall is above 430mm has been increasing since 1984. This could be attributed to global warming changing the climate.



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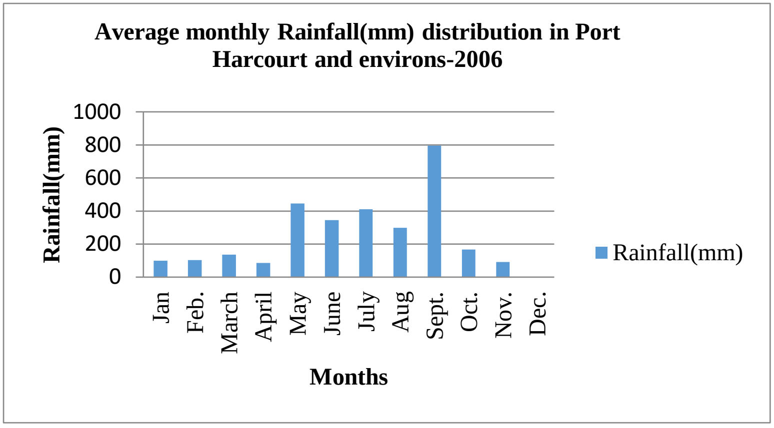

Fig. 2: Average Rainfall Distribution charts of Port Harcourt and environs for 2006 and 2008

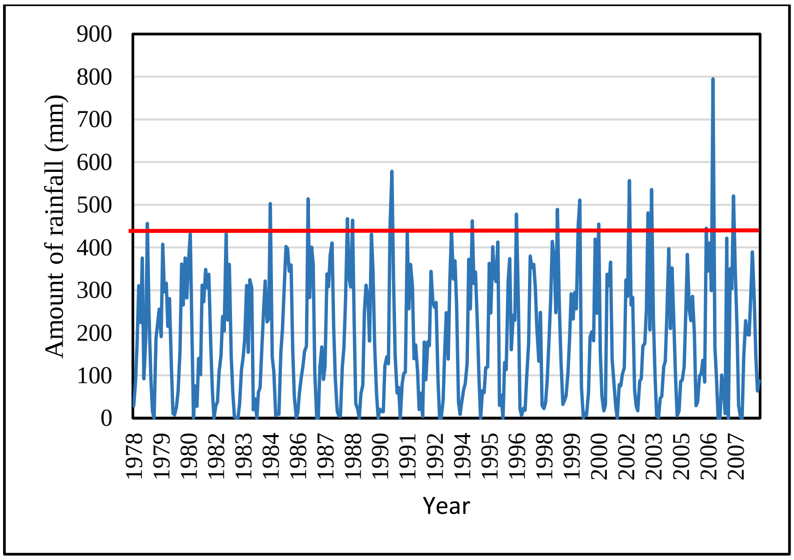

Figure 3: Average yearly amount of rainfall between 1978 and 2008.

Weather Temperature

The temperature of an area plays a very important role in assessing the overall availability of surface water in an area as it controls the evaporation from the open surface as well as evapo-transpiration from the vegetated area. As shown in the temperature distribution charts (Fig. 4), the maximum temperature normally recorded during day time range from 29.8 to 35.5^{0}c and the highest temperature always occurs between January and April which is dry season period. The minimum temperature normally recorded in the night, range from 20.6 to 23.4 ^{0}c and the lowest temperature in the night is always recorded in January as a result of cold harmatan breeze.

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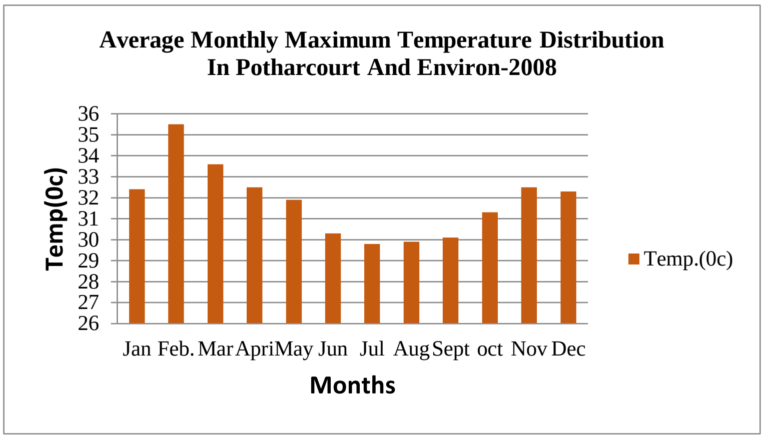
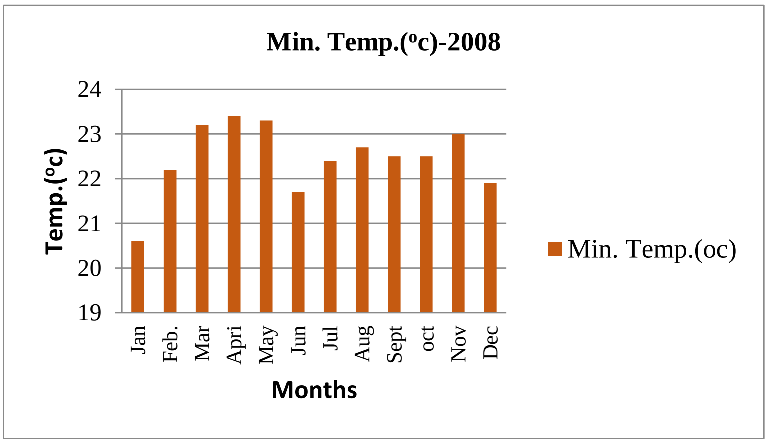


(a)



(b)

Fig. 4: Temperature distribution chart of Port Harcourt

Figure 5 shows that the average maximum weather temperature for Port Harcourt and environs have been rising in a zig-zag like form since 1978. The trend line shows a gradual rise in temperature. Temperature has risen from 30.78^{0}c in 1978 to 31.84.0^{0}c in 2008 (i.e. within 30 years). This gradual rising temperature is obviously an evidence of gradual climate change and can be attributed to global warming. The positive correlation between the years and the average maximum weather temperature with a correlation coefficient (R) of 0.73 indicate that the temperature will continue to rise if factors responsible for global warming remain. Therefore, using the regression equation to predict future temperature, after another ten years, which is 2018, the average maximum weather temperature should not be less than 32^{0}c.

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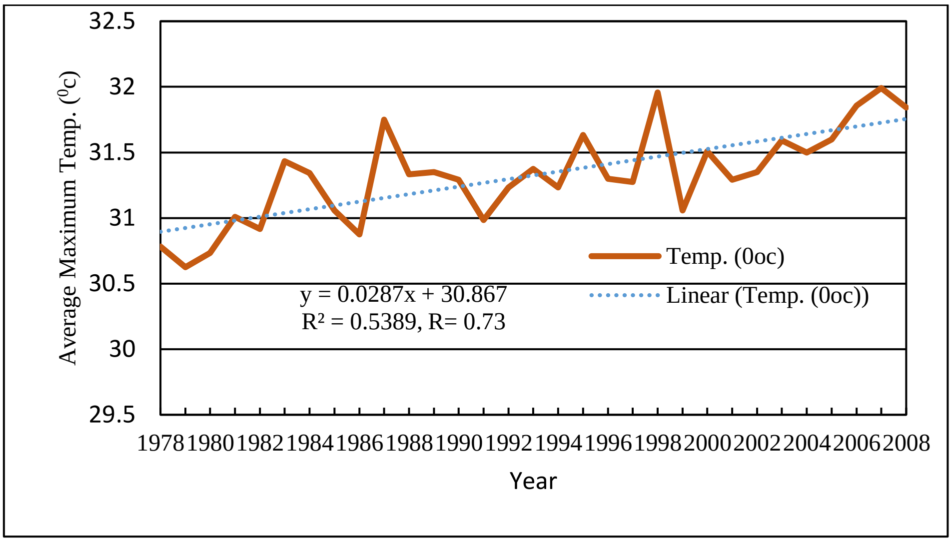

Figure 5: Average maximum temperature between 1978 and 2008. It shows gradual increase in weather temperature.

Potential Impact of Climate Change on Groundwater

The hydrogeological and meteorological settings of Port Harcourt indicate the availability of robust groundwater resources. The dry/harmatan season (local climate change), though associated with high evaporative demand from soils, surface water and very shallow aquifers, does not have adverse significant effect on ground water storage due to short duration. Except the very shallow hand-dug wells of about 6 to 9m depth, no water borehole of not less than 22m depth has been reported got dried up during the short period of no rain. The yearly long period of effective rainfall and permeable overlying soils ensure adequate replenishment of the unconfined aquifer. The thick layers of soils prevent evaporation from the groundwater storage. So it is a challenge to exclusively establish a direct quantitative relationship between groundwater and global climate change. The challenge is also compounded by the dearth of information on the quantitative estimate of the volume of groundwater in Port Harcourt. Even the availability of historical records of the yearly/seasonal variations of water level depth in the different parts of city is doubtful. No records to ascertain if the groundwater resources have decreased, increased or remain stable over the years. Even if there are records to show that it has decreased over the years, how do we ascertained it is due to over-pumping or climate change? Therefore, for now, the impact of global climate change on groundwater resources can be relative on it impact on the surface water.

It is an established fact that stream flow is sensitive to climate change (Mahe, 2009). For example, in May 2017, the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) announced that Lake Chad is drying up due to climate change. Also, in May 2016, the Federal Government of Nigeria, warns that the river Niger is drying up due to climate change and dumping of industrial waste. Hydrogeologically, it is expected that the water table of the aquifer in the flood plains recharged by the water-bodies should also be dropping gradually. Therefore, groundwater resource is related to climate change through the direct interaction with surface water resources and indirectly through the recharge process (Kumar, 2012).

Port Harcourt is characterised by creeks, rivers and some locations of very shallow aquifer that can be impacted directly by climate change. Some of the consequences of the impact that will indirectly or remotely affect the groundwater resources in Port Harcourt are as follows:

1. Sea Level Rise and Salinity Intrusion.

Port Harcourt is a coastal city with lowlands, creeks and rivers (Fig. 1). Some areas in the city such as Borokiri, Abonema, Eagle Island, Port Harcourt Beach, Ugboshimini, and Bundu are close to tidal channel that connects directly to the Atlantic Ocean (Oteri, 1990; Amadi 1990). These areas depend on coastal deltaic unconfined aquifer with shallow water table. The depth of the base of the freshwater lens is between 30 and 45m (Ukpaka and Chinedu, 2016). Should global warming continue to cause sea level rise, the coastal aquifer is at the risk of salinity intrusion- the replacement of fresh water in coastal aquifer by saltwater (Fetter, 1988; Kumar, 2012). Salinity intrusion will reduce the harvestable fresh water resources in the aforementioned areas.

2. Frequent Heavy Rainfall and Associated Flooding

Global warming affects local and regional hydrological cycle by increasing evaporation and precipitation. Warm air holds more moisture and increase evaporation from soil and surface water bodies (Kumar, 2012). Since Niger Delta where Port Harcourt is located is proliferated with swamps, rivers and creeks, and close to the sea, there is more than enough moisture to evaporate resulting in more frequent intense rainfall in the region as temperature increases. Therefore, the positive impact on the groundwater is that the aquifer will be continuously recharged.

The water table in Port Harcourt is shallow (0.5 to 10m depth) (Amadi, 2010). The overlying soil type ranges from clayey sand, silty sand to fine-grained sand with moisture content that ranges from 22 to 34% (Nwankwoala and Udom, 2014). Also, the creek and rivers within the city have shallow overbank. The water holding capacity of soil can be exceeded during frequent heavy rain resulting in high over-land flow and flooding (Ehirim and Nwankwo, 2010). When the water holding capacity of the drainage facilities (gutters and culverts) in the city are exceeded and the rivers overflowed their banks, you have catastrophic flooding. During such flooding, surface contaminants are mobilized and pollute the groundwater resources through the boreholes that remain inundated for couple of days. Therefore, the most likely negative impact of climate change on ground water resources is reduction of the quality and not the quantity.

3. Prolong Dry/Hammatan Season

Climate change could also manifest in the form of gradual increase in dry/hammatan season duration resulting in gradual drop in water table due to over-pumping (mainly) and intense evaporation without proportionate recharge of the aquifer. From the foregoing, a situation of drought in which dry season duration is almost equal or more than that of rainfall is very unlikely in Port Harcout. It can happen in the northern part of the Country-Nigeria. As long as the duration of steady rainfall remains more than that of dry season, Port Hacourt should continue to have robust groundwater resources.

CONCLUSIONS

1. Global warming is permanently changing the climate. It causes frequent intense rainfall, sea level rise, flooding etc. Port Harcourt is part of the globe and is not exempted from the effects of climate change. Groundwater is impacted directly through surface waters and indirectly through the amount of rainfall (i.e. recharging processes). With thick and permeable aquifer, steady rainfall almost throughout the year and permeable overlying rock materials that permit infiltration, Port Harcourt has robust groundwater resources. However, the shallow coastal aquifers in some locations are at the risk of saltwater intrusion if the sea level keeps rising.

2. Port Harcourt is a coastal city, with lowlands, lots of fresh water swamps, rivers/streams trending channels of shallow slope and low overbanks. Therefore, the city is prone to flooding. The combination of seal level rise and intense frequent rainfall due of climate change will result in catastrophic flooding.

3. Aquifers in Port Harcourt that is naturally well covered with clayey sand (laterite) have been punctuated with numerous private boreholes. When flooding occurs, some of these boreholes are inundated. Surface pollutants that have been mobilized by flood get into the aquifer and pollute the groundwater resulting in gradual diminution of its quality. Therefore, the proliferations of private boreholes should be discouraged, while the development of central freshwater supply project by the government should be highly encouraged. Also, the culture of environmental sanitation should be sustained and intensified to reduce the amount of pollutants mobilized during flooding.

4. Climate change may manifest as unusual prolong dry/harmatan season resulting in significant drop in water table. But due to the regional location of Port Harcourt, drought is believed to be unlikely.

5. This study is a preliminary one towards the study of effects of climate change on groundwater resources in Port Harcourt. Further studies should include the estimation of the rate of groundwater recharge, the determination of the volume of groundwater, and periodic monitoring and recording of its quality and depth.

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REFERENCES

1. Fetter, C.W., 1988. Applied hydrogeology. Merril Publishing Co., USA. 592p.
2. Taylor, R. G. Koussis, A.d. and Tindigugaya, C. 2009. Groundwater and climate in Africa- A review. Hydro. Sc. J, 54(4): 655-664.
3. Amadi, A. N., 2010. Effects of urbanisation on groundwater quality: A case study of Port Harcourt, Southern Nigeria. Natural and Applied Science Journal, 11(2): 143-152.
4. Bates, B. C., Kunzewicz, Z.W., Wu, S. and Palutikof, J. P. 2008. Climate change and water. Technical Paper VI of the Intergovernmental Panel on Climate Change (IPCC), IPCC Secretariat, Geneva, 210p.
5. Kumar, C. P. 2012. Climate Change and its Impacts on Groundwater Resources. International Journal of Engineering and Science, 1(5): 43-60.
6. Treidel, H. Martin-Bordes, J. L. And Gurduk, J. 2012. Climate change effects on groundwater resources. A global synthesis of findings and recommendations. Balkema Book, Taylor & Francus Group, London, UK, 399p.
7. Short K.C., Stauble A.J. 1967. Outline Geology of the Niger Delta. Am. Ass. Petroleun Geologists Bull., 51: 761-779.
8. Reijers, T.J.A., 2011. Stratigraphy and sedimentology of the Niger Delta. Geologos, 17 (3): 133–162.
9. Weber, K.J. and Daukoru, E. M., 1975. Petroleum geology of Niger Delta. Proc. 9th world petro. Congr., Tokyo. 2: 209-221.
10. Adelana, S.M.A., Olasehinde, P.I., Bale, R.B., Vrbka, P., Edet, A.E, & Goni, I.B., 2008. An overview of the geology and hydrogeology of Nigeria, in Applied ground water studies in Africa, p171-197. Publ. Taylor & Francis Group, London, UK.
11. Offodile, M. E. 1992.An approach to ground water study and development in Nigeria. Mecon, geology and Engineering services, Jos. 247p.
12. Amajor, L. C. 1986. Geochemical characteristics of groundwater in Port Harcourt and environs. Proceedings of NWASA Symp. Lagos, pp. 354-376.
13. Amajor, L. C. 1991. Aquifers in the Benin Formation (Miocene to Recent) Eastern Niger delta, Nigeria: Lithography, hydraulics, and water quality. Environ. Geol. Water sc. 17(2): 85-101.
14. Nwankwoala, H. O. and Udom, G. J. 2014. Investigation of hydrochemical characteristics of groundwater in Port Harcourt City, Nigeria. J. Appl. Sc. Environs. Manage, 15 (3): 479-488.
15. Ukpaka, C. P. And Chinedu U. 2016. Characterisation of groundwater in Port Harcourt local Government Area. Journal of Advances in Environmental Sciences, 1(2).
16. Iloeje. N.P. (1972). A New Geography of West Africa, Longman Group Limited, Nigeria.
17. Mahe, G. 2009. Surface/ groundwater Interactions in Bani and Nokambe Rivers, Tributaries of the Niger and Volta basins, West Africa. Hydro. Sc. J, 54(4): 704-712.
18. Oteri, A. U. 1990. Delineation of saltwater intrusion in coastal beach ridge of Forcados. Journal of Mining and Geology, 26(1): 31-45.
19. Amadi, U. M. P., 1990. Saltwater intrusion in the coastal aquifer of southern Nigeria. Journal of Mining and Geology, 26(2):35-44).
20. Ehirim, C. and Nwankwo, C. N. 2010. Evaluation of Aquifer characteristics and groundwater quality using geoelectric method in Choba. Archives of Applied Science Research, 2(2): 396-403.