International Journal of Earth Sciences Knowledge and Applications
www.ijeska.com

Research Article e-ISSN: 2687-5993

Assessment of the Influence of Groundwater Level and Chemistry on Concrete Foundations Around Ifite Awka, Anambra State, Nigeria

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INFORMATION

Article history
Received 29 October 2020
Revised 18 December 2020
Accepted 22 December 2020
Available 15 March 2021

Keywords
Groundwater level
Quality
Permissive limit
Concrete
Foundation

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ABSTRACT

Water is a vital necessity for human existence; howbeit it has been a major concern over the years especially in the built industry where structural integrity has remained a mirage. Groundwater conditions especially the chemical composition and its potential attack on concrete foundations is paramount toward ensuring safe and economic design of structures. The presence of sulphate, chloride as well as pH above the permissible limits in groundwater may result to deterioration of either the concrete itself or the steel reinforcement. This condition if not checked overtime may ultimately lead to structural collapse resulting to loss of lives and properties. Also, increase in groundwater level can either delay or bring construction activities to abrupt end due to uncontrollable influx of water especially during excavation. Thirty water samples were collected from wells and boreholes in different locations within the study area and subjected to chemical analysis in accordance with NIS, BS, DIN and WHO standards to determine their degree of corrosivity on concrete foundations. Six wells were also monitored to determine the extent of groundwater level fluctuation. The result of the analysis indicated a pH value of 4.8 to 10.6 with mean temperature of 25.48°C. Seven out of 30 samples tested for iron exceeded the permissive limit. The sulphate value ranges from 10 to 230 mg/L while chloride content is from 10 to 180 mg/L among others. The groundwater level monitoring revealed a seasonal pattern of fluctuation influenced by rainfall. It is recommended that precautionary measures be taken against groundwater conditions and its effect on concrete foundations in the study area and should be considered at the design stage.

1. Introduction

Water is life; it is essential natural resources needed for man, plants and animals to survive. It is also useful for domestic, agricultural, and industrial purposes. It is in recognition of this fact that International organizations, including the UN member states set aside 22nd of March every year as World Water Day. Regardless of the numerous contributions of water resources in human development, it can also constitute a problem if not properly considered in certain circumstances (Ofusu et al., 2014). Obiadi et al. (2011) stated that rainfall intensity is a primary factor that influence gully erosion in south eastern, Nigeria. Onunkwo et al. (2017) evaluated the role of groundwater in pollution status of Awka, Anambra State of Nigeria.

In construction industry, groundwater level fluctuation may significantly affect the bearing capacity of soil which may lead to major modification of initial project design or abandonment in cases of excess ingress of groundwater during excavation (Preene et a., 2000; Price, 2009; Rahardjo et al. 2010). Groundwater plays a dominant role in the generation and spread of many problems of geotechnical origin during excavation, mining, tunneling and various forms of earthworks. In such instances, lowering of the groundwater level (dewatering) may be necessary to achieve smooth operation. The alarming evidence of rising shallow groundwater level and the wide spread structural problem have warranted the extra demand to develop special geotechnical awareness, standard testing and designing procedures to minimize the impact of wetting on soil behavior (Stipho, 1993). Concrete is commonly made up of water, aggregates and Portland cement; with cement acting as the binder when mixed with water. Cement contains lime, alumina, iron oxide and silica in varying proportion with the principal cementing compound being calcium aluminate ($CaO \cdot Al_2O_3$).

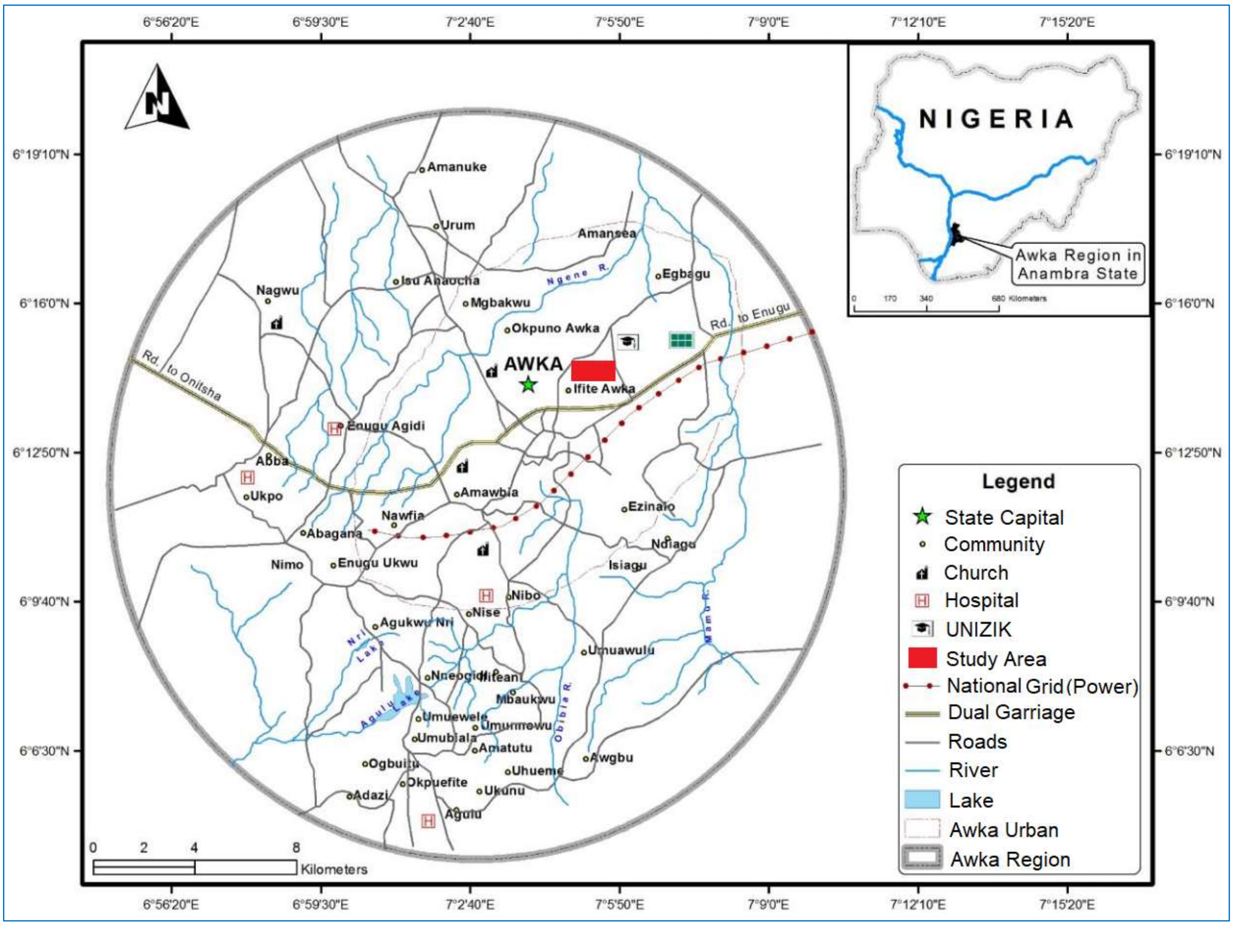

Fig. 1. Location and drainage map of the study area

Kucche et al. (2015) established that impurities present in water react differently with different constituent of cement. These reactions mostly affect the setting time, compressive strength and may also cause straining of concrete surface. Kucche et al. (2015) also recorded that concrete serves as shield for reinforcement, therefore chemical attack on concrete due to aggressiveness of groundwater may result in deterioration of either the concrete or the reinforcement itself. At low pH, free lime present in concrete which is responsible for protecting the steel by providing alkaline environment is compromised. Sulphate in water reacts with calcium silicate hydrates (C-S-H) responsible for strength in concrete to form ettringites, thereby weakening the concrete (Ofusu et al., 2014; Kabashi et al., 2017).

The presence of Chloride in water and oxygen induces corrosion in steel through the process of carbonation (Ofusu et al., 2014; Adewole et al., 2015; Kucche et al., 2015; Kabashi et al., 2017).

Although geotechnical investigations are pre-requisite to attaining safe and economic design of any civil engineering structures, many researchers believe that groundwater conditions especially the chemical composition and its potential attack on concrete foundation is one of the parameters needed to guarantee structural stability (Stipho, 1993; Preene et al., 2000; Ofusu et al., 2014; Kucche et al., 2015; Olorunfemi et al., 2017). Olorunfemi et al. (2017) reported different effects of underground water in buildings around Ilorin to include saturated walls, deep crack walls, discoloration of walls, wall plastering and paint film flake-offs. Ofusu et al. (2014) recorded high values of pH and Chloride concentration above permissive limits in Dangbe East-West Districts of the Greater Accra Region of Ghana.

He attributed his result to the close proximity of the study area to the sea. Preene et al. (2000) evaluated groundwater chemistry and its influence on the selection of tunnel construction materials in Sweden and concluded that Sulphate resistant grout be used as a remedy for sulphate attacks.

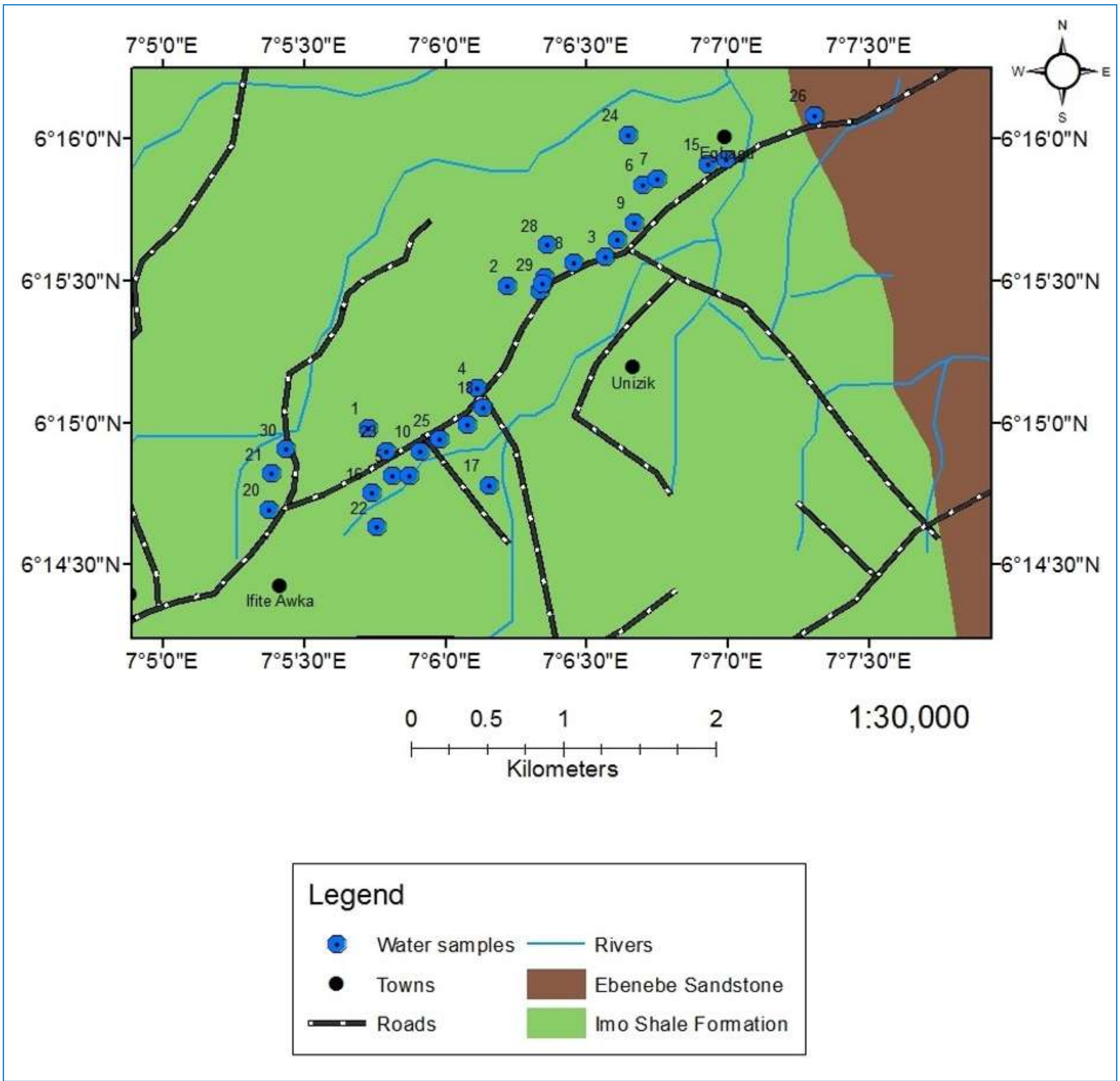

Fig. 2. Geologic map of the study area showing the water sample locations.

In Awka, the occurrences of groundwater with high concentration of iron could aid or enhance corrosiveness in reinforcements. It is therefore imperative that the groundwater conditions of the study area be established prior to the commencement of construction activities. Subsequently, this paper presents the assessment of groundwater samples obtained from both wells and boreholes around Ifite, Awka; the results were used to determine the potential attack on concrete foundations by comparing the values with international standards.

2. Description of the Study Area

The study area is located in Ifite-Awka, the capital territory of Anambra State, South Eastern Nigeria. It lies between latitude 6°7'30"N - 6°16'30"N and longitude 7°1'30"E - 7°7'30"E (Fig. 1). The study area is of great significant because it is the host community for both State and Federal establishments like Nnamdi Azikiwe University, Anambra State secretariat etc, hence active in terms of infrastructural development. The landform is undulating with both high and lowlands. The climatic condition is generally warm and humid with two major seasons- rainy and dry seasons, and annual rainfall of about 2000 mm (Ofomata, 1975; Okoro et al., 2010). Its vegetation can be described as tropical rainforest belt of West Africa (Okoro et al., 2010; Enaworu et al., 2017). The trees which grow in clusters are up to 6-7metres tall, interspersed with grasses which grow up to about three meters. However, most of the original rain forest in the study area has been severely reduced to Savannah vegetation due to anthropogenic activities.

3. Geology of the Study Area

The study area lies within the Anambra basin formed due to subsidence of the Anambra plate resulting to folding and uplift of the Abakaliki-Benue fold belt in the Santonian stage (Egboka et al., 2006). The basin is dominantly filled with clastic sediments constituting several distinct lithostratigraphic units deposited from lower Campanian to Recent (Murat, 1970). The lithostratigraphic units have a thickness of up to 2,500 m. The study area (Fig. 2) is underlain by the following subsurface geology: Imo Shale (Paleocene), which is a sequence of grey shales with occasional clay, ironstones and sandstone beds of several meters in thickness. The Imo Formation is described by Reyment (1965), Nwajide (2013) and Chiaghanamet al. (2014), to consist of fine texture, grey and bluish-grey shale with occasional clay ironstone, thin sandstone and sandy limestone bands. The Formation becomes sandy towards the top where it may contain alternation of bands of sandstone and shale. The shale consists predominantly of dark grey carbonaceous shale with sandy limestone. The Nanka Sand is composed of very loose, flaser-bedded units of fine to medium grained sand, with a few mudrock breaks. The sand consists of sub-rounded to sub-angular grains and has an average of 5% clay content which makes it texturally sub mature (Chiaghanam et al., 2014).

4. Methodology

The field work started with monitoring of groundwater level fluctuation. This was done by taking the measurement of the depth of groundwater in six (6) wells within the study area for two seasons (rainy and dry) using a piezometer. The seasonal groundwater level variation was obtained by calculating the difference in depth of groundwater in the monitored wells over the two seasons, measured in meter. A total of thirty (30) groundwater samples labeled W1-W30 were carefully collected from wells and boreholes in the study area (Fig. 2) and preserved in clean plastic containers before taken to the Anambra State Materials Testing Laboratory for the analysis. The laboratory analysis was carried out according to the World Health Organization standard (WHO, 2011). However, water quality evaluations were assessed by comparing their properties with the maximum allowable limits set by European Standard for Testing Mixing water for concrete, (BS EN 1008, 2002), World Health Organization standard, (WHO, 2011) and Nigerian Industrial Standard, (NIS-554, 2018) for water and chemical analysis. pH was determined using pH meter while TDS, Salinity and conductivity was determined by Conductivity meter. All other parameters were determined using Titration method. The coordinate of the study area was measured using a GPS. Hydrologic map was produced using Surfer 11.

5. Results and Discussions

This section presents the outcome of both field and laboratory investigations. The results of the laboratory analysis and the statistical summary of the groundwater parameters are shown in Tables 1 and 2.

5.1. Hydrologic delineation

The static water level measurement obtained from the study area was used to produce a hydrologic map of the area using surfer 11 software (Figs 3 and 4). The recharge and discharge areas are also indicated in the map. The recharge area is located on the topographically high land of Ifite-Awka, from Aroma Farms downward to St. Anthony Catholic Church, while the discharge area is low land around University School Gate towards Amansea (Fig. 3). Fetter (2001) suggested that flow lines tend to diverge from recharge areas and converge towards the discharge area which is evident from the groundwater flow direction on the map.

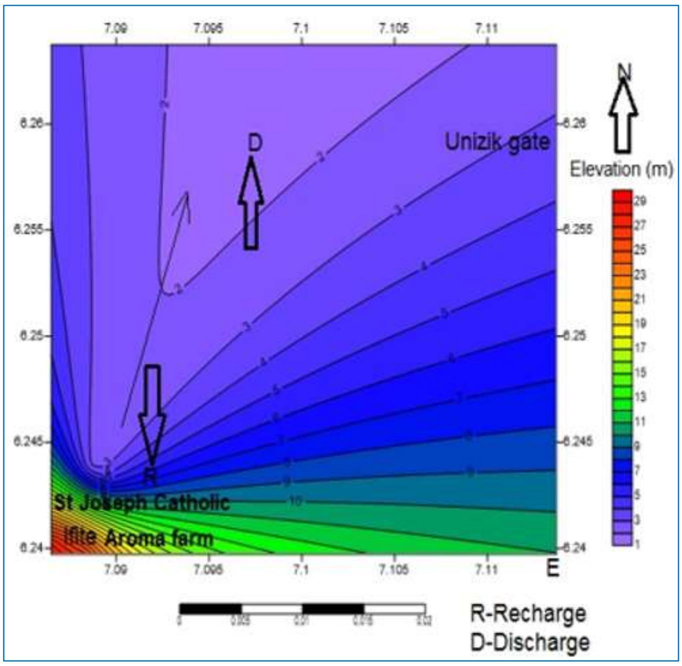

Fig. 3. Hydrologic map of the study area

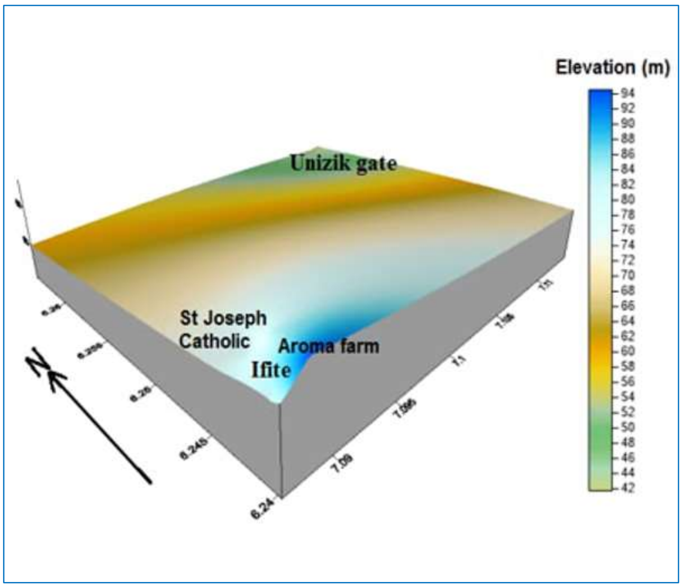

Fig. 4. Hydrologic map of the study area in 3D

5.2. Groundwater level variation

A total of six (6) wells were monitored for groundwater level variation in the study area. These wells are designated as well 1-6. The monitoring was done in the months of June, 2019 and February, 2020 representing the two seasons peculiar to the study area: rainy and dry herein referred to as WET 1 and DRY 1. The details of the well locations, elevation as well as depth to groundwater (static water level) are shown in Table 1. The groundwater level monitoring shows a seasonal pattern of fluctuation influenced by rainfall. During the rainy season, the maximum groundwater level recorded was 28.3 m while the minimum depth was 2.31 m. At the peak of dry season, the water level depths of the same wells were measured. Maximum depth to groundwater was at 30.23 m whereas minimum depth was 4.04 m. Thus, the seasonal groundwater level variation measured in meters ranges from 0.99 m to 2.42 m with an average depth of 1.82 m. The plot showing the depth variation in meter is shown in Fig. 5.

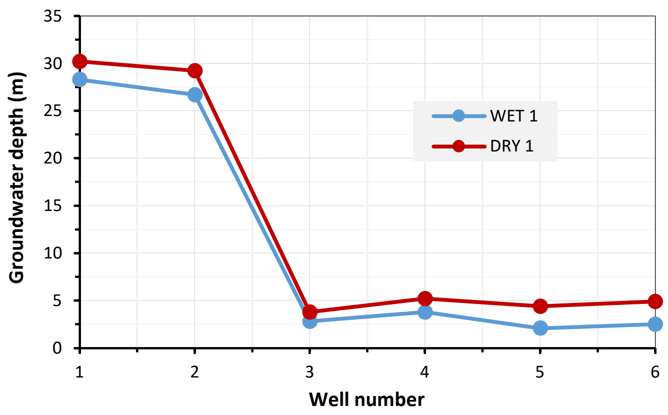

Fig. 5. Water level variation graph

The high groundwater level acts to extend the capillary zone upward, while lower level develop suction in the soil pores and negative pore water pressure that causes soil particles to move closer to each other (Stipho, 1993). This unarguably increases the soil strength. Wells 4, 5, and 6 are located in relatively lowland areas with water close to the surface, therefore water can push against the underside of the foundation in a condition known as "hydrostatic pressure" thereby causing water to infiltrate through the bottom of the foundation. Capillary rise may occur in soil above the water table in this area which can cause deterioration to structures. Furthermore, the areas are prone to water logging especially at the peak of rainy season thereby hindering construction activities in which case dewatering might be an option. This condition may also be unfavorable to concrete foundation especially if the groundwater is corrosive.

5.3. Chemical Analysis

5.3.1. Temperature

The result of temperature of the water samples tested ranges from 22.5°C to 27.0°C with a mean temperature of 24.6°C. Although temperature changes quickly, it has an impact on other parameters such as pH.

5.3.2. Conductivity

Conductivity values range between 7.44µS/cm and 3900µS/cm with mean value of 1354.32 and variance of 1641468 (Table 2). The large variation in conductivity values obtained could be attributed to anthropogenic activities in the area. Samples W6, W8, W13, W14, W15, W16, W19, W20, W22, W23, W25, W26, W27, W29, W30, representing about 50% of the total samples tested exceeded both WHO (2011) and NIS (2015) standards for conductivity of water for drinking and industrial purposes. According to (Todd and Mays, 2005), conductance increases with salt content.

5.3.3. pH

This is an essential parameter because most geochemical processes are pH sensitive. The samples recorded minimum pH value of 4.8 and a maximum value of 10.6 while the mean value is 6.9 (Table 2). According to WHO (2011), NIS (2015) and DIN 4030-1 E (1991) range of 6.5 to 8.5, sample W8 exceeded the standard limit of water for both drinking, industrial and concrete mixing, respectively, while samples W1, W2, W3, W9, W10, W17, W20, W21, W26 and W28 are below the standard (Fig. 6). This implies that about 33.3% of all samples tested are moderately acidic water. However, with regards to BS EN 1008 (2002) standard of water quality for concrete, the pH ranges from 4.0- 8.5, thus only sample W8 failed to meet the standard. It can be deduced from pH scale that about 57% of the samples are acidic. Ofusu et al. (2014) recorded that water with pH below 6 is a potential treat to concrete foundation, however the degree of attack of water tested can be regarded as weak (Table 3). This may also have the tendency to corrode pipes and other metal fittings it comes in contact with in a building.

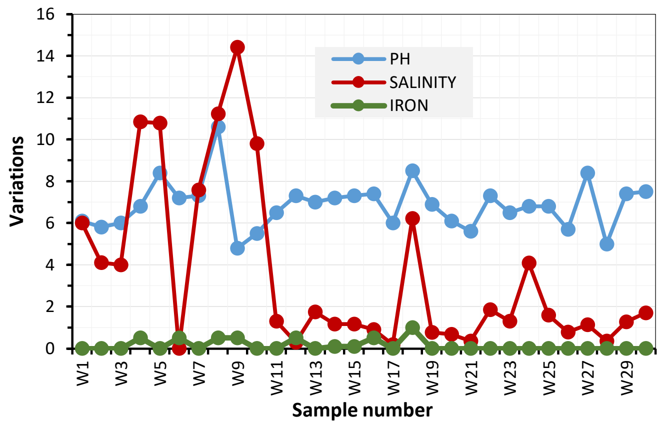

Fig. 6. pH, salinity and iron concentration

5.3.4. Salinity

The salinity of all the samples tested fall within the NIS (2015) standard of water for industrial activities as indicated in Fig. 6 with values ranging from of 0.19-14.42. The standard deviation is 4.08 (Table 2). Although the compressive strength of concrete tends to increase with saline water, research has shown that salinity in water actually increases the risk of corrosion of embedded reinforcing steel, if the structure is to be exposed to air service (Akinsola et al., 2012). Salinity can also result to dampness on concrete surface, howbeit, the problem of salt attack varies depending on the type of salt and its deteriorating mechanism which could be either physical attack, chemical attack or corrosion of reinforcement.

5.3.5. Sulphate

The sulphate concentration values as obtained from the analysis indicate a range of 10mg/L to 230mg/L with mean value of 51.03mg/L. It can be inferred from Fig. 7 that only samples W6 and W30 exceeded the allowable industrial limit of 100mg/L as stipulated by NIS (2015) while only W30 exceeded the WHO (2011) standard for drinking water.

The presence of sulphate in groundwater can allow sulphate-reducing bacterial in an anaerobic condition to produce sulphides and subsequently sulphric acids which are very corrosive to cast iron and steels (Preene et al., 2000). This sulphate attacks the structural elements of a foundation such as shotcretes to form ettringites causing swelling, cracking and weakening of the shotcretes. The sample W30 signifies an expected weak corrosiveness towards concrete durability according to DIN 4030-1 E (1991) (Table 3). Although to the samples W3, W4, W15, W19, W23 and W25 which recorded concentrations within acceptable limits, they can still be considered a risk factor due to its high values.

Table 1. Location, static water level and elevation of monitored wells

Well number	Coordinates		Elevation (m)	Static water level (m)		Static water level variation (m)
	Latitude	Longitude		WET 1	DRY1	
1	6°14'22.16"N	7° 5'11.52"E	123	28.30	30.23	1.93
2	6°14'23"N	7°5'18"E	109	26.8	29.15	2.35
3	6°14'38"N	7°5'19"E	81	3.05	4.04	0.99
4	6°14'32.85"N	7° 6'11.66 E	87	3.9	5.0	1.1
5	6°15'46"N	7°6'51"E	44	2.31	4.42	2.11
6	6°15'50.6"N	7°6'45.4"E	45	2.48	4.90	2.42

Table 2. Statistical summary of groundwater parameters

Parameters	Number of samples	Minimum	Maximum	Mean	Standard deviation	Variance	(NIS, 2015)	(WHO, 2011)
Temperature (°C)	30	22.5	27.5	25.48	1.22	1.48	Ambient	-
pH	30	4.8	10.6	6.86	1.17	1.38	6.5-8.5	6.5-8.5
EC (μs/cm)	30	7.44	3900	1354.32	1281.2	1641468	1000	500
Salinity	30	0.19	14.42	3.59	4.08	16.67	700	-
TDS	30	3.72	1948	677.6	641.19	411132.8	500	500
Hardness (mg/L)	30	0.0	255	75.87	66.79	4460.46	150	500
Ca^{2+} (mg/L)	30	0.0	230	50.83	53.74	2888.11	200	75
Mg^{2+} (mg/L)	30	0.0	155	25.04	34.13	1164.93	20	30
SO_4^{2-} (mg/L)	30	10	230	51.03	41.89	1754.45	100	200
Cl^{2-} (mg/L)	30	10	180	37.73	33.73	1137.91	250	250
Fe^{2+} (mg/L)	30	0.0	1.0	0.14	0.26	0.07	0.3	0.3
NO_3^- (mg/L)	30	1.0	7.0	3.0	1.70	2.90	50	45

Table 3. limiting values for evaluating the degree of attack of waters on cement-bound materials (DIN 4030-1 E, 1991)

Sample	Investigations	Degree of attack		
		Weak attack	Strong attack	Very strong attack
1	pH Value	6.5 to 8.5		
2	Lime dissolving carbon dioxide (CO_2) mg/L (Marble dissolving experiment after Heyer)	15 to 40	> 40 to 100	> 100
3	Ammonia (NH_4^+) mg/L	15 to 30	> 30 to 60	> 60
4	Magnesium (Mg^{2+}) mg/L	300 to 1000	> 1000 to 3000	> 3000
5	Sulphate (SO_4^{2-}) mg/L	200 to 600	> 600 to 3000	> 3000

5.3.6. Magnesium

Magnesium concentrations of samples tested though have no significant consequences on concrete foundation as confirmed by DIN 4030-1 E (1991) (Table 3), is considered to be of very high concentration with values ranging from 0.1mg/L to 155mg/L (Fig. 10). The allowable limit as stipulated NIS (2015) for industrial use is 20mg/L, while WHO (2011) specified 30mg/L for portable water. Among the samples tested, samples W1, W3, W4, W5, W7, W9, W11, W13, W24, W25, W27 and W30 are above both specified limits representing 40% of the total samples.

5.3.7. Calcium

Values obtained from the analysis are between 15mg/L to 230mg/L with a mean value of 50.83mg/L and Standard deviation of 53.74 (Table 2).

NIS (2015) stipulated a maximum limit of 200mg/L for water used for industrial purposes, thus samples W6 and W18 are above this limit while six samples (W4, W6, W8, W18, W19 and W24) did not meet the WHO (2011) standard for drinking water of 75mg/L. This implies that 91.7% of the samples tested are within specification.

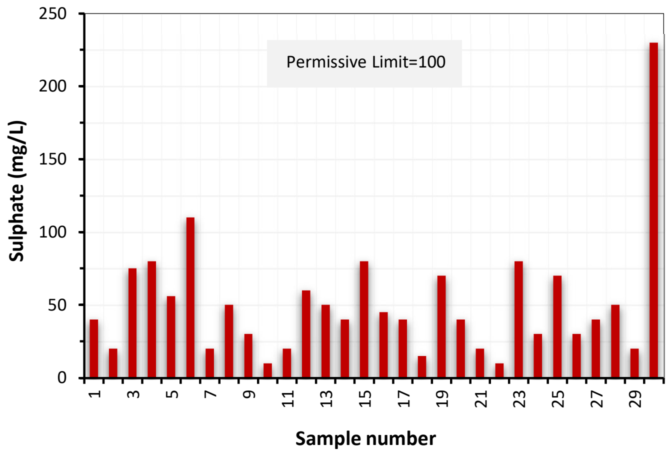

Fig. 7. Bar representation of sulphate concentration

5.3.8. Chloride

The chloride concentration ranged from 10mg/L – 180mg/L with mean value of 37.87mg/L and variance of 1137.91. As presented in Fig. 8 below, all samples tested are within both WHO and NIS specifications of 250mg/L according to WHO (2011) and NIS (2015), respectively. The favorable result can be attributed to the geology of the study area, since high concentration of chloride are likely to be found near sea, area periodically flooded by sea water as well as region where water evaporates easily from the soil. Chloride attack is primarily the cause of corrosion of reinforcement (Preene et al., 2000; Ofusu et al., 2014; Adewole et al., 2015; Kabashi et al., 2017). The protective oxide film present on the surface of steel reinforcement can be lost due to carbonation by chloride in the presence of water and oxygen. However, sample W30 with concentration of 180mg/L could be considered a high risk which can make concrete foundations in that area susceptible to chloride attack in near future through processes like capillary absorption and diffusion depending on the position of structures relative to the mean water level (Kabashi et al., 2017).

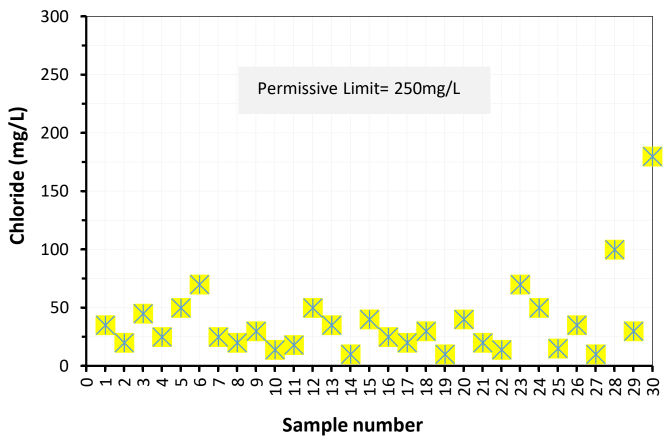

Fig. 8. Representation of chloride concentration

5.3.9. Iron

Iron concentration obtained from the analysis varies from 0.1mg/L to 1.0mg/L with mean value of 0.14 and standard deviation of 0.26. Fig. 6 shows that seven (7) out of thirty (30) samples tested exceeded both WHO and NIS standards with a maximum value of 1.0 while others are within the portable and industrial tolerable limit of 0.3 according to WHO (2011) and NIS (2015) specifications, respectively. Ezeabasili et al. (2014) also recorded Fe^{2+} concentrations in the water samples from Awka ranging from 1.20mg/L -5.00 mg/L. Oxidation of ferrous iron to ferric iron may be favoured by low pH amongst other factors, giving an objectionable reddish-brown color to the water which does not present an aesthetic appeal to household plumbing materials like toilets and other household items.

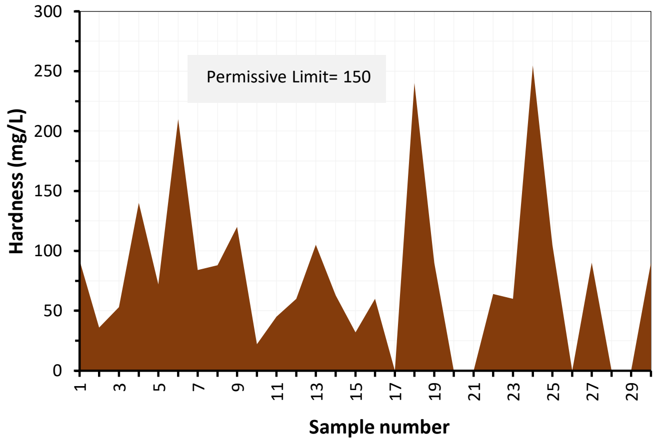

Fig. 9. Graphical representation of hardness

5.3.10. Hardness

The hardness value as represented in Fig. 9 ranges between 22 and 255. With reference to BS EN 1008 (2002) permissive limit of 150, samples W6, W18 and W24 did not meet the specification. This represents about 12.5% of the total sample tested. Whereas W4 and W9 are within the specified limits, they can be considered a risk factor because of the significant concentration recorded. Classifying these samples according to Sawyer and McCarty (1967), the degree of hardness varies from soft to hard water (Table 4). Whilst water hardness may be of less consequence to concrete, extremely hard water may most likely increase stalagmites and stalactites as deposit from hard water leaving “scale” on pipes and faucets.

Table 4. Hardness classification of water (Sawyer and McCarty, 1967)

Hardness mg/L as $CaCO_3$	Water class
0 - 75	Soft
75 - 150	Moderately Hard
150 - 300	Hard
Over 300	Very hard

5.3.11. Nitrate

Nitrate concentration ranges between 1.0mg/L to 7.0mg/L with a mean value of 3.0mg/L (Table 3). All samples tested for nitrate concentration fall below the portability and industrial maximum allowable concentrations of 45 and 50mg/L of water for WHO (2011) and NIS (2015), respectively (Fig. 10). This can be related to the less agricultural activities in the study area. Nitrate ions have the ability to bind to certain solid phases, therefore it is often used in form of Calcium Nitrate to produce an accelerating admixture used to optimize performance of concrete and shorten the set time. However, Franke (2014) suggested that nitrate act as either corrosive chemical or corrosion inhibitor depending on its dosage and the type of cement. It could also increase the risk associated with Nitrate Stress Corrosion Cracking (NSCC) in Steel.

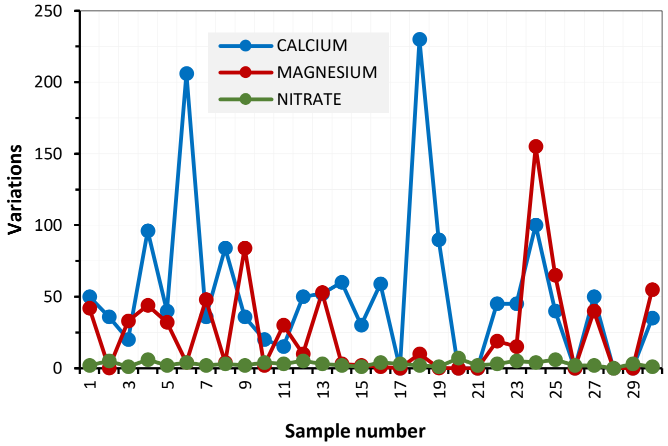

Fig. 10. Ca^{2+}, Mg^{2+} and NO_3^- concentration

6. Conclusion

This study examined in detail the influence of groundwater level fluctuation and chemical composition on the stability of engineering structures around Ifite, Awka in South East, Nigeria, using hadrochemical tools. The groundwater level revealed seasonal variation largely influenced by rainfall with a maximum depth of 28.3 m and minimum depth of 2.31 m during the rainy season while in the dry season maximum depth of 30.23 m and minimum depth of 4.04 m was recorded with an average depth variation of 1.82 m. This explains the presence of both deep and shallow wells reflecting the topography of the study area. The shallow wells mean the groundwater level is close to the surface. The pH is essential because of its influence on most geochemical processes. High sulphate concentration was recorded which may encourage the formation of ettringite causing swelling, cracking and weakening of foundation element. Iron concentration was observed to be above recommended limits in seven out of thirty samples tested (W4, W6, W8, W9, W12, W16, and W18). High Iron concentration in the presence of other elements like sulphate and chloride could aid corrosion of reinforcement bars used in construction. The results of this study will be useful in rehabilitation and reconstruction of structures that are already under distress as a result of the groundwater influence. Also, proper documentation of this investigation is recommended for future design and construction of structures in the area. It is recommended that hydrogeologist, materials and metallurgical engineers should be engaged at the early stage of construction planning during construction to evaluate the effects of groundwater level and chemistry on foundations. This will help in decision making with respect to choose of materials to be used.

Acknowledgement

The authors wish to appreciate everyone who contributed to the success of the work, especially the management and staff of Anambra State Materials Testing Laboratory for their assistance in the course of this research.

Conflict of Interest

Authors herein declare that there is no competing interest.

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