Groundwater Vulnerability Assessment of Obafemi Awolowo University Campus, Ile-Ife, Southwestern Nigeria

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Abstract

The groundwater vulnerability assessment of Obafemi Awolowo University campus, Ile-Ife, Southwestern Nigeria was carried out using the modified DRASTIC technique, with a view to determine the degree of vulnerability of the groundwater within the area. The study revealed that the area is subdivided into High (2%), Moderate (8%) and Low (90%) groundwater vulnerability regions. The Low groundwater vulnerability region is the most predominant based on the prevailing hydrogeological conditions of geology, lineament density, slope, and thickness of weathered layer. The Low groundwater vulnerability region is most suitable for locating waste dumps, and most of the waste dumps are well situated within this region. However, care should be taken in the development of the site to avoid the reduction or complete removal of the topsoil through excavation; or increasing the permeability of the area through boring of open holes. These processes would increase the vulnerability of groundwater resources.

Keywords: *DRASTIC technique, groundwater occurrence, groundwater pollution, hydrogeology, waste management*

INTRODUCTION

Surface water and subsurface water (groundwater) are the two main sources of water available to man for use. Surface water resources, when exploited can become short in supply, may be degraded in quality or may not be readily available on site. Groundwater is the major source of freshwater on earth, excluding icecaps and glaciers; and its development is cost-effective compared to surface water development. The need for groundwater exploration has become necessary in recent times due to the growing demand for fresh and reliable sources of water. Where available, groundwater can be a very important complement to augment surface water supplies.

Even though groundwater generally has better quality than surface water (Ighalo and Adeniyi, 2020), indiscriminate exploitation reduces the quantity of available groundwater; while human activities such as the application of fertilizers to soil, sewage disposal and sanitary dumps tend to impair the quality of groundwater available for use (Bayowa *et al*., 2012; Ighalo and Adeniyi., 2020). Water can therefore be rendered unsuitable for its intended use when contaminated through human activities.

Groundwater in the Basement Complex environment such as the Obafemi Awolowo University (OAU) campus, southwestern Nigeria, occurs in pore spaces present in the weathered material or within cracks and sheared zones in fresh basement rock. Groundwater accumulation in the Basement Complex rocks depends on the degree of weathering and thickness of the weathered material, the nature of the weathered material and the connectivity of the pore spaces. Thick weathered layer of relatively coarse material will favour groundwater accumulation. The greater the connectivity of the pore spaces, the higher the permeability of the material.

The volume of the pore spaces in a soil determines the amount of water that it can contain. Highly porous soil would accommodate greater amounts of water than less porous soil because of its large volume of pore spaces. Clayey materials generally absorb and hold large amounts of water, but the hydraulic conductivity which is the ease with which the material allows the flow of water through it is rather slow. This is because of the electrostatic force of attraction between the clay particles and the water molecule. Hence, the hydraulic conductivity of clayey materials is low. The hydraulic conductivity of soil, which is closely related to its permeability, will increase with the reduction in the clayey content of the soil material (Bilardi *et al*., 2020; Ajayi *et al*., 2020). Therefore, when precipitation reaches the surface of the earth, some amount of it flows through the soil material in a process of infiltration, until the soil is fully saturated. The remaining part of the precipitation flows on the surface of the earth as runoff.

Precipitation which infiltrates into the earth recharges the groundwater aquifer, carrying dissolved material from the atmosphere, surface of the earth and topsoil. Therefore, the chemical property of the water which recharges the groundwater aquifer depends on the path length of the water. Chemical constituents deposited on the earth surface and in surface water have been found in groundwater due to the processes of infiltration and percolation (Nevondo *et al*., 2019; Ajani *et al*., 2020). Likewise, poisonous materials dumped on the earth surface and in surface water dissolves in water during infiltration and percolation processes and are carried into groundwater. The consumption of water contaminated with poisonous materials causes diseases and could lead to death (WHO, 2015).

Groundwater contamination is a global problem which could cause water diseases such as cholera, diarrhoea, syphilis, and typhoid. Although there is no available data specific on the estimate of casualties of groundwater contamination, about 500 million children below the age of 5 in Asia, Latin America and Africa suffer from diarrhoea annually. In developing countries, over 40% deaths are ascribed to infections from contaminated water (Adejuwon and Mbuk, 2011). Groundwater contamination could be because of natural or anthropogenic effects. Groundwater contamination due to natural effects depends on the geological materials through which the groundwater flows through. Groundwater flowing through geological materials dissolves and carries ionic compounds of magnesium, iron, potassium, calcium, nitrate, chloride, sulphate, fluoride, and arsenate, depending on the composition of the geologic material. When the concentration of these naturally occurring elements in the groundwater exceeds the tolerance level of humans, it causes water borne diseases and death of humans.

Anthropogenic sources of pollution of water include industrialization, intense agriculture, rapid urbanization, and growing demand for energy (Mustapha and Getso, 2014). Anthropogenic effects on groundwater could be in the form of industrial waste such as dyes, agricultural wastes such as fertilizers and insecticides, and other domestic human wastes that impact heavy metals such as lead, copper, arsenic, and mercury on groundwater. Over 2 million tons of anthropogenic wastes find their way into surface water which consequently impact the groundwater (UN WWAP, 2003).

Developing countries such as Nigeria have problems with waste management and control hence, indiscriminate waste dumps are a common sight. Indiscriminate dumping and growth of waste materials in Nigeria has resulted into flooding when waste materials block water channels and drainage; surface water pollution from suspended and decomposing materials carried into water bodies (Amuda and Alade, 2006), and groundwater contamination resulting from the percolation of heavy and trace metals such as lead, cadmium, zinc, iron, nitrate and copper from waste materials and polluted surface water into groundwater (Oyedele *et al*., 2008; Obase *et al*., 2009; Cobbina *et al*., 2014; Ganiyu *et al*., 2016).

Poor waste management therefore renders groundwater vulnerable to contamination. Groundwater vulnerability mapping has been employed in developing groundwater resource protection strategies. Groundwater vulnerability map is a guide that shows how vulnerable groundwater is within the mapped area. Groundwater vulnerability map is based on the fundamental concept that groundwater is generally vulnerable to contamination in various degrees. Groundwater vulnerability is not directly measurable, rather it is a relative and dimensionless property. Groundwater vulnerability mapping involves simplifying complex geological and hydrogeological processes operating in the given area. The idea of groundwater vulnerability assumes that the geologic materials provide some degree of protection for the groundwater from surface contaminants. The geological materials serve as natural filters during infiltration and percolation processes to screen contaminants.

Several approaches such as the DRASTIC and GOD techniques have been developed for use in assessing the groundwater vulnerability of an area. There are merits and demerits of each method and there is no method that is most appropriate for all situations (Foster *et al*., 2002). Most Groundwater vulnerability assessment approaches are essentially hydrogeology oriented and subjective (Oni *et al*., 2017), while a few electromagnetic parameters such as longitudinal conductance and terrain conductivity embrace geophysical approach of measurement.

The DRASTIC approach of groundwater vulnerability mapping is a combined description of the key geological and hydrogeological influences on groundwater movement, into, through and out of an area (Gennaro, 2001). The DRASTIC technique which considers depth to groundwater table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and hydraulic conductivity (C); takes into consideration more hydrogeological parameters compared to the GOD technique which considers three (3) parameters of groundwater confinement (G), overlying strata (O) and depth to groundwater (D).

Fresh crystalline basement complex rocks such as those in Southwestern Nigeria does not have the capacity to hold groundwater because it has negligible porosity or fractures. Hence, groundwater occurrence in the basement complex environment is mostly within the shallow weathered overburden or in fractures within the basement rock. The OAU campus in southwestern Nigeria is underlain by basement complex rocks with groundwater occurring within the porous shallow overburden material of maximum thickness of about 70 m (Konwea, 2021) and fractured/sheared basement rocks (Olorunfemi *et al*., 2020). The shallow nature of the basement rock aquifer within the OAU campus has made the area vulnerable to groundwater contamination. There is therefore the need to assess the groundwater vulnerability of the OAU campus in line with the prevailing hydrogeological setting to ascertain the extent of vulnerability of the groundwater.

Study Area

The study area is the OAU campus located partly in Ife Central and Ife North Local Government Areas of Osun State, southwestern Nigeria (Fig. 1). The study area is 56 km^2 and the topography consists of low lands and highlands. The area is covered by inselbergs in the northern part and dissected pediments around the inselbergs. The hills have an average altitude of 400 m above mean sea level and serve as watershed for the rivers draining the campus. The OAU campus is drained by Rivers Shasha and Opa. These rivers and their tributaries form the network of drainage systems found within the OAU campus. The study area is located within the tropical rain forest belt of southwestern Nigeria, with separate wet and dry seasons, resulting from the movement of different air masses. The south-westerly wind is responsible for the wet season while the north-easterly wind is responsible for the dry season. The wet season runs from April to November, spanning about 8 months while the dry season runs from November to March, spanning about 4 months. The southwestern Nigeria in which the study area falls within, receives an average annual rainfall of 1500 mm from the eight (8) months duration of rainfall (Ayoade, 1975) and temperature extremes of 19^{o}C and 35^{o}C (Ajayi and Abegunrin, 1990).

The OAU campus is situated in a Basement Complex environment with potential for surface and groundwater resources. The area has witnessed remarkable infrastructural development to support the consistent growth in the population of students, staff, and academic programmes. The surface water supply from the Opa reservoir within the precinct of the OAU campus no longer meets the water needs of the over 30,000 population (Konwea *et al*., 2021). Therefore, borehole and hand-dug well construction accompanied infrastructural development to meet the water needs of the University community.

Currently, there is heavy dependence on groundwater within the OAU campus. Areas such as the Teaching and Research Farm, University Conference Centre, Muritala Mohammed Postgraduate Hall of residence and around Roads 8, 10, 22 and 24 of the

Senior Staff Quarters, rely partially or totally on groundwater, while the Adeshakin Female Hostels, along Ede Road, OAU Campus; and the Moro Campus of the Centre for Distance Learning (CDL) rely totally on groundwater. Groundwater within the OAU Campus results from the infiltration and percolation of precipitation from the surface of the earth into the groundwater reservoir.

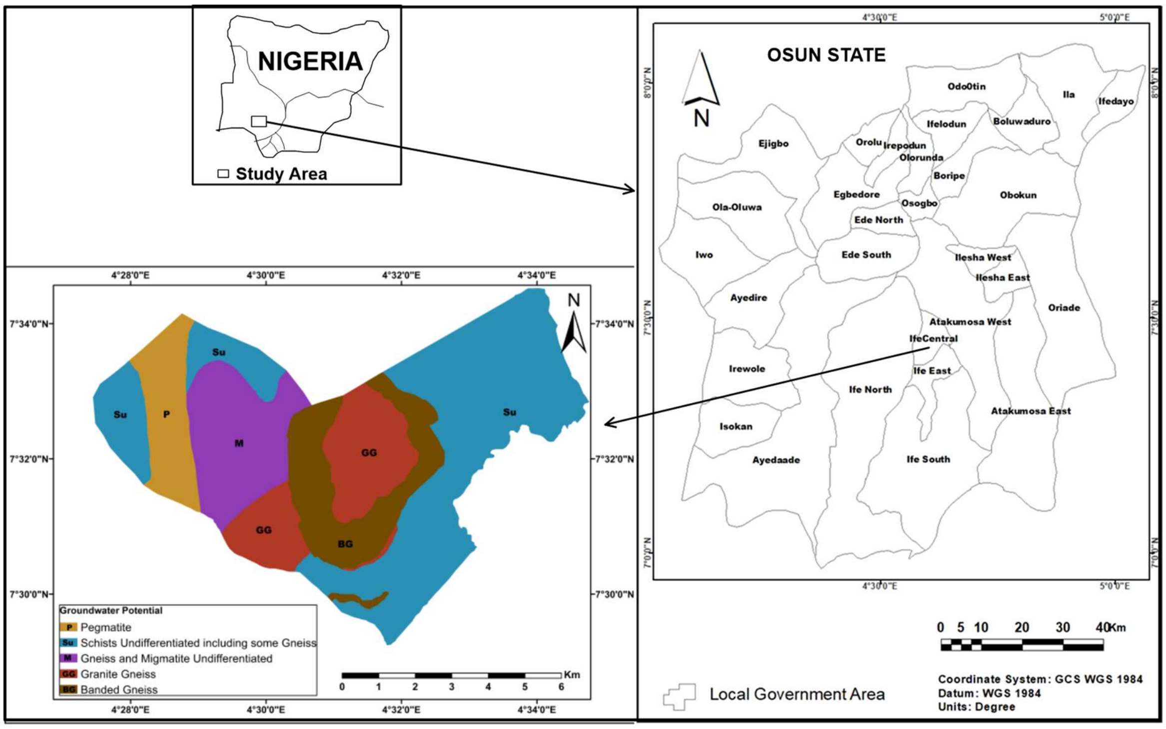

Figure 1: Location of OAU Campus

However, the occurrence of wastes generated from point and non-point sources around the OAU campus threaten the potability of the groundwater and the health of the over 30,000 population relying on the groundwater for their water needs. The point sources of waste are waste locations that are discrete with little variability over time such as waste dumps and landfills. The non-point sources of waste are diffused waste sources with no definite or specific location where discharge to the surrounding takes place such as agricultural fields and construction sites. The OAU community generates domestic, agricultural, and industrial wastes at point and non-point sources. The large population of the OAU community generates domestic and municipal wastes capable of releasing heavy metals and enteric human pathogens into the groundwater body. For instance, most of the municipal wastes in OAU campus are transmitted through a network of pipes to an Oxidation Pond, south of the campus, where it undergoes treatment before discharge into River Opa. Chemical analysis of soil samples around the Oxidation Pond indicated high concentrations of Pb, Cr, Zn and Cu; suggesting that the groundwater within the vicinity of the Oxidation Pond has been contaminated (Bayowa *et al*., 2012). The covers 15 km^2 OAU commercial, and teaching and research farms make use of pollutants (fertilizers, insecticides, and waste water). These pollutants and sediments are transported to receiving streams and groundwater bodies by periodic storm water. Also, animal residues and decaying plants generate large quantities of pollutants capable of impacting the surface water and groundwater bodies. The several construction sites and industries (water treatment facility and bottle and sachet Water Company) generate industrial wastes that are directly discharged or partially treated before discharge into the environment. In highly vulnerable aquifers systems, wastes greatly impact the groundwater, posing serious health hazards including environmental problems (Adepelumi *et al*., 2001; Tijani *et al*., 2002; Obase *et al*., 2009). In fact, soil and groundwater contaminations have been reported in some areas of the OAU campus (Adepelumi *et al*., 2001; Bayowa *et al*., 2012; Joe-Ukairo and Oni, 2018).

The DRASTIC approach of groundwater vulnerability mapping which require information on depth to static water level, groundwater recharge, aquifer and soil media, topography, vadose zone, and hydraulic conductivity has proved effective in assessment of groundwater vulnerability within crystalline Basement Complex environment (Jaseela *et al*., 2016; Asiwaju-Bello *et al*., 2020). Hence, the DRASTIC approach would effectively assess groundwater vulnerability within the OAU campus as it puts into consideration several hydrogeological parameters which influences groundwater occurrence and transport within the crystalline rock environment such the OAU campus. However, the groundwater vulnerability map of the OAU campus was generated using modified DRASTIC parameters because of availability of data.

METHODOLOGY

The groundwater vulnerability map of OAU campus was generated from the spatial attributes of geology, lineament density, slope, and thickness of the weathered zone. The geological map of the OAU campus was employed. Fine grained materials such as clay and silt as well as fresh bedrock on the earth surface decrease soil permeability and restrict contaminant transport through the attenuation of contaminants (Todd and Mays, 2005). These areas were rated low in order of pollution potential. Areas with thick medium to coarse weathered material can attenuate the filtration process of percolating water. These areas were rated high in terms of pollution potential. Based on contaminant attenuation effect, composite map of bedrock and soil type effect on the groundwater beneath OAU campus was generated.

This study made use of the Landsat 8 OLI Imagery derived from satellite image, SRTM data to generate lineaments. The data were acquired from the United States Geological Survey (USGS) via online source. The Landsat OLI has a resolution of 28m. Other items used include the ENVI 5.0, PCI Geomatica 2013 and ArcMap 10.4 software. The short-wave infrared (SWIR) range (Band 6) of the Electromagnetic spectrum and the ENVI 5.0 were used to apply contrast stretching to the Band 6 raster file. Contrast stretching improves the visual quality of bands through increased range of digital number (DN). This range is usually between 0 and 225. Spatial filtering of the image involving 3 x 3 kernel convolution and median filters, and high pass edge enhancement filtering were applied using the convolution and morphology filter module (ENVI 5.0). Based on morphological spatial filtering, automatic lineament extraction was carried out for edge and sharpening enhancements. The output of the identified lineaments was further enhanced by applying the line module of PCI Geomatica. The extracted lineaments were superimposed on the False Colour Composite (FCC) of Bands 6, 4 and 2, and lineaments corresponding to undesired features such as river channels, roads, settlement, and other manmade features were removed. The resulting lineaments were finally superimposed on the digital elevation map, and those lineaments corresponding to high elevations such as hills were deleted, leaving only the hydrogeologically significant lineaments (Bayowa *et al.,* 2014).

Slope percentages for the OAU campus were computed using the Digital Elevation Model (DEM) data. The slope percentages were used to produce a composite map of the OAU campus.

In obtaining the vadose zone thickness, 104 VES stations were established along farm edges, footpath and edges of road and open fields within the OAU campus (Fig. 2). The location and running of the VES profiles were carried out away from drainage pipes and electrical cables to avoid interference. The electrode spacing (AB/2) was varied between 1 m and 150 m, and the apparent resistivity (ρ) obtained. The data interpretation involved plotting of the apparent resistivity data, partial curve matching and computer iteration technique. The depth from the earth surface to the fresh basement was taken as the thickness of the weathered zone.

The modified DRASTIC approach was used to generate the groundwater vulnerability map of OAU campus. The seven DRASTIC technique parameters of depth to groundwater table, net recharge, aquifer media, soil media, topography, impact of vadose zone and hydraulic conductivity were modified into geology, lineament density, slope, and thickness of weathered layer. The parameters employed in the groundwater vulnerability assessment were based on importance and availability of the data. Composite maps of the geology, lineament, slope, and thickness of the weathered layer were weighted, ranked, and overlapped based on weight percentage using the GIS tool to obtain the groundwater vulnerability map of the study area.

It is pertinent to state here that the groundwater vulnerability map does not consider the physical or chemical nature of the pollutant in the groundwater vulnerability assessment. The hydrogeological settings necessary for groundwater susceptibility to contamination from surface sources were the only parameters considered in this study.

Although both point and non-point sources of waste are generated within the OAU campus, only the locations of point sources of wastes within OAU campus were mapped using the

GPS. The locations of the waste dump sites were superimposed on the groundwater vulnerability map to determine the suitability of the sites for waste dump.

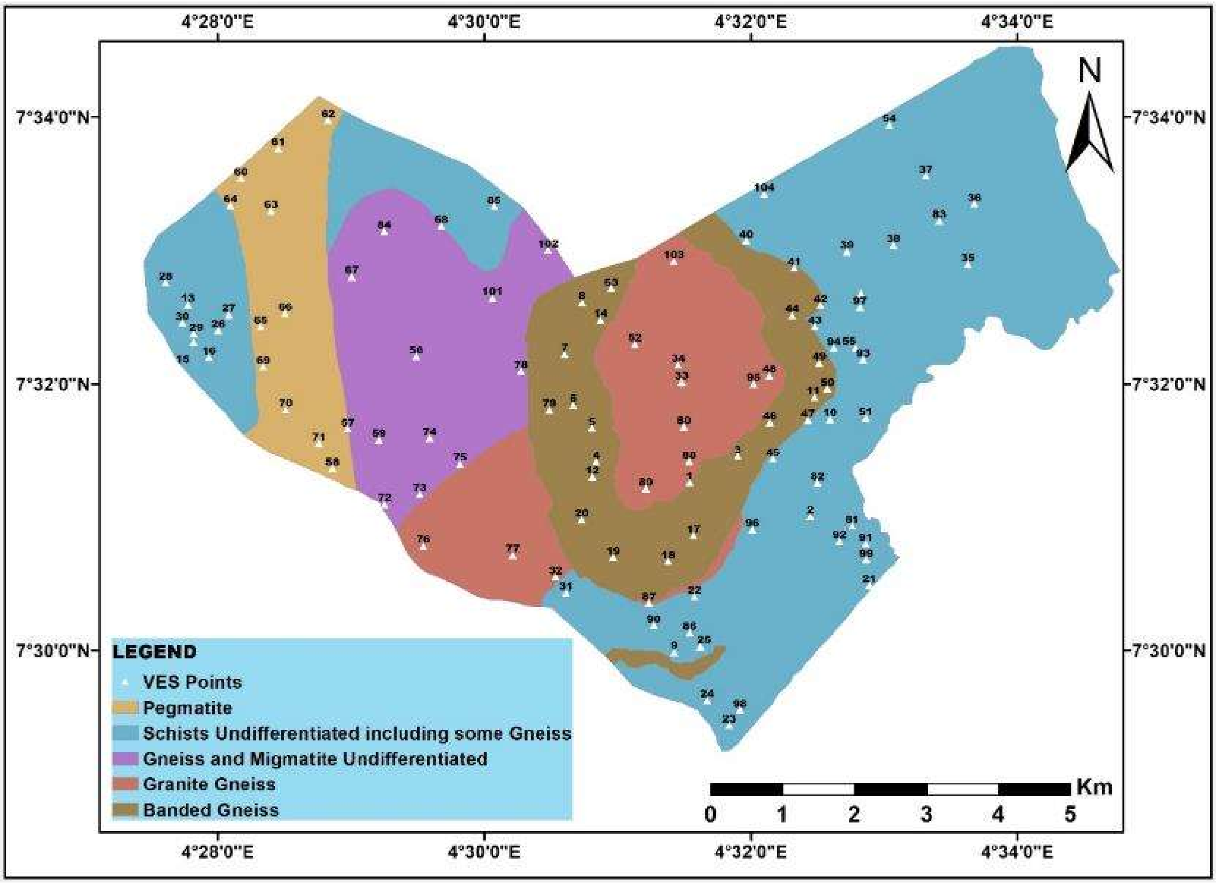

Figure 2: VES Locations within OAU Campus

RESULTS AND DISCUSSION

The groundwater vulnerability map of OAU campus was generated based on the modified DRASTIC technique (Aller *et al*., 1987). The four (4) parameters employed in this study were based on the limited available data. These parameters include geology, lineament density, slope, and thickness of weathered layer.

Assessment of Modified DRASTIC Parameters

Geology

The OAU campus is underlain by five (5) major rock types (Fig. 1), that have undergone fracturing and weathering due to tectonic and climatic activities. The vulnerability of the fractured rocks and their weathered derivatives as well as their ability to absorb and transmit contaminants and other dissolved ions in water varies across the rock type. The difference in chemical and physical weathering as well as the difference in the susceptibility of the rocks are responsible for the variation in vulnerability of the rock materials. The increasing ability of the rocks in the study area to absorb and transmit water include schist undifferentiated, gneiss and migmatite undifferentiated, granite gneiss, banded gneiss, and pegmatite. The higher the rate of absorption and transmission of water by the fractured rocks and their weathered products, the higher their vulnerability to absorption and transmission of dissolved ions and other constituents.

Schist is a high-grade metamorphic rock that contains mainly biotite and muscovite. Weathered schist gives rise to clayey materials with low permeability, restricting the flow of groundwater through it. Hence, schist is highly susceptible to absorption and transmission of dissolved ions and other constituents. Gneisses are metamorphic rocks that occur in continuous bands of light and dark minerals. The light minerals contained in the light bands are predominantly quartz and feldspar, while the mafic minerals contained in the dark bands are predominantly mica and amphibole. In addition to the enhanced permeability of gneiss caused by the coarse grain of quartz, the weathered mafic minerals in the dark bands of the gneiss act as transmission path for groundwater. Pegmatite has large grain sizes that are prone to fracturing, thereby increasing the porosity and permeability of the pegmatite. Weathering of pegmatite results in the formation of coarse-grained quartz embedded in finer grains of sandy to clayey materials. The interconnected pore spaces in the weathered pegmatite act as storage and transmission path for groundwater, making pegmatite highly vulnerable to absorption and transmission of dissolved ions and other constituents. The relative porosities of schist, gneiss and pegmatite are such that gneiss < schist < pegmatite (Ozbek *et al*., 2018; Plunder *et al*., 2022), hence the occurrence of water in these rocks as well as their weathered derivatives would be in that same order.

The larger pore spaces in coarse grained weathered material influence pore space interconnectivity and greater groundwater occurrence and transmission compared to fine grained material. The decreasing order of groundwater vulnerability of the rock types based on coarse nature of the weathered material, degree of fracturing and the presence of bands is pegmatite > schist > gneiss.

Lineament Density

The lineament map of the OAU campus was generated from the analysis and interpretation of Landsat-8 imagery of the area (Fig. 3). The occurrence of hydro-lineaments indicates that groundwater could be accommodated and transmitted through lineaments (Akinluyi *et al*., 2021). Drainages that flow along the path of a lineament are said to be structurally controlled (Shahzad *et al*., 2009). Structurally controlled drainages are influenced by major tectonic elements and the discontinuities in the underlying rock could be sources of groundwater discharge or recharge. The process of groundwater recharge is what transport contaminants from the earth surface into the groundwater in the subsurface (Cobbina *et al*., 2014). In addition to the presence of porous and permeable geologic materials, lineaments facilitate groundwater recharge (Abdullahi *et al*., 2013; Mogaji *et al*., 2011). High lineament density areas are associated with greater groundwater recharge and higher groundwater pollution potential. Areas with low lineament density are associated with lesser groundwater recharge and lower groundwater pollution potential (Edet *et al*., 1998; Mogaji *et al*., 2011; Abdullahi *et al*., 2013; Sarikhani *et al*., 2014). Therefore, the rapid groundwater recharge through lineaments reduces pollutant attenuation effect of the surface water and runoff, causing dissolved ions and other constituents carried from waste materials to find their way into groundwater.

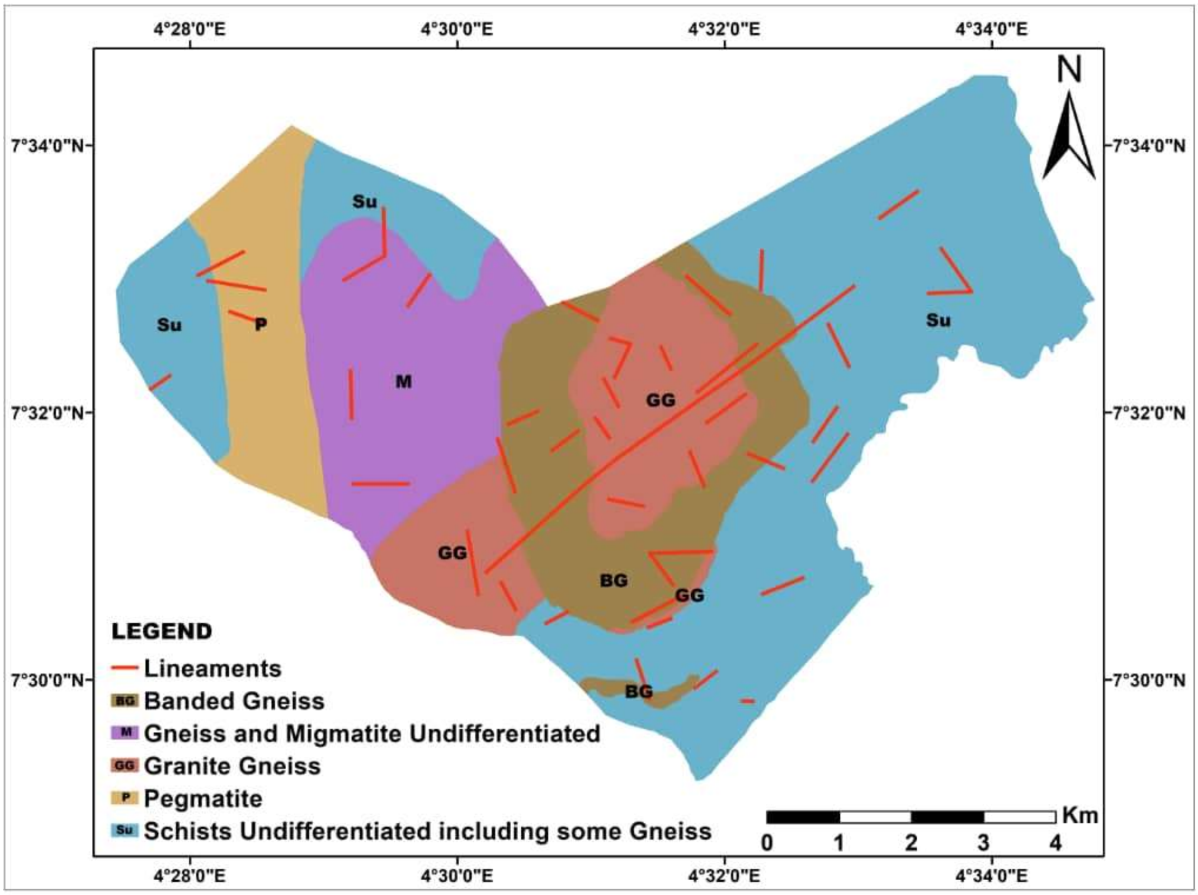

Figure 3: Lineament Map of OAU Campus (Konwea *et al*., 2023)

Forty-one (41) lineaments were delineated within the study area, out of which twenty-six (26) lineaments, representing 64% occur within the gneiss. Twelve (12) lineaments, representing 29% occur within the mica schist. The remaining three (3) lineaments, representing 7% occur within the pegmatite.

Akinluyi *et al*. (2021) demonstrated that groundwater accumulation and transmission are influenced by increasing length per area of lineaments. Therefore, the tendency for dissolved ions and other constituents to be transmitted through lineaments increases with increase in the length per area of lineaments. The degree of transmission of dissolved ions and other constituents into groundwater by the lineaments within the OAU campus was classified based on lineament length and interception. For simplicity, the lineaments within the study area were categorised into three (3) groups of high, medium, and low groundwater vulnerable lineaments (Fig. 4). Lineaments with length greater than 2 km fall within the category High and were labelled "a". Lineaments with lengths between 1 km and 2 km were categorized as Medium and labelled "b". Lineaments that form intercept with a combined length of between 1 km and 2 km were categorized as Medium and labelled "b". Lineaments with length of less than 1 km were categorized as Low and labelled "c". Lineaments with high groundwater vulnerability occur around the central part of the study area, trending NE-SW. Lineaments with medium to low groundwater vulnerability are evenly distributed and trend in almost all directions within the OAU campus.

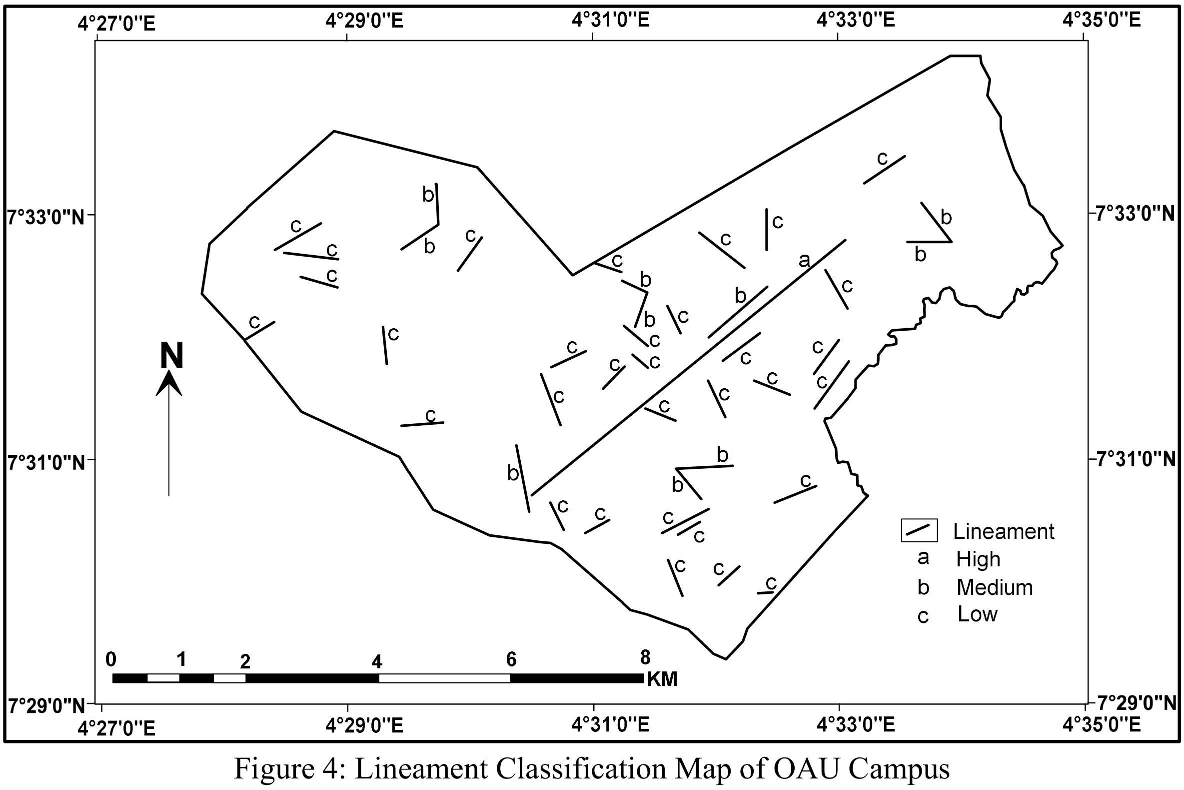

Figure 4: Lineament Classification Map of OAU Campus

Slope

The effect of topography on the groundwater contamination within the OAU campus was considered as the slope, and slope variability within the OAU campus. Topographic variation within the OAU campus controls contaminant runoff or retention on the surface and contributes to groundwater recharge within the area. Areas with steep slope have less chances of contaminant infiltration into the subsurface. Instead, the contaminant will flow downslope leaving concentrated contaminants at the base of the slope where the topography is relatively flat (Akinfaderin *et al*., 2019). The gradient map of the OAU campus was generated from the Landsat-8 imagery (Fig. 5). Grinevsky (2014) established that in most geologic materials, higher topographic gradient favours more surface runoff and less infiltration whereas low topographic gradient favours less surface runoff and more infiltration. When groundwater recharge occurs in a rapid manner in relatively low gradient terrain, there would be less time for pollutant attenuation in the water, leading to high groundwater vulnerability. When groundwater recharge occurs in a slow manner in relatively high gradient terrain, there would be more time for pollutant attenuation in the water, leading to low groundwater vulnerability.

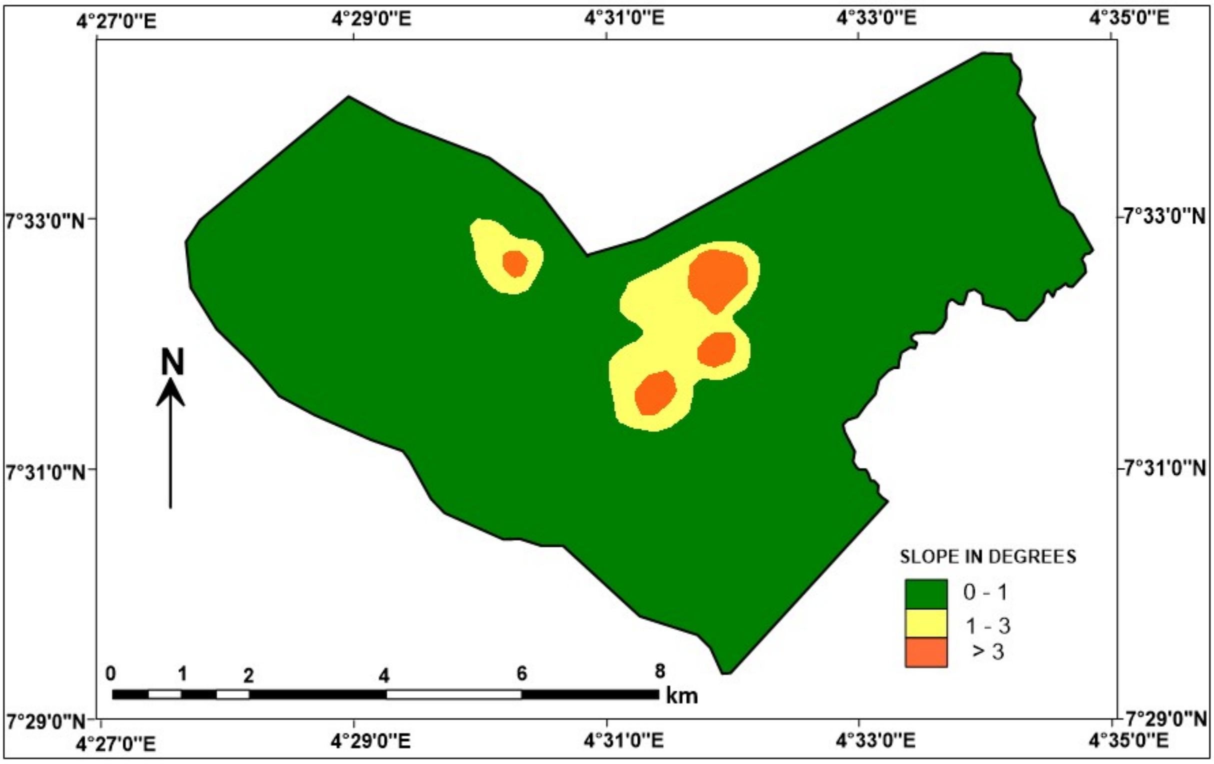

Figure 5: Gradient Map of OAU Campus

The central part of the OAU campus with relatively higher gradient of between 1° and 3° will experience lower groundwater recharge with lower groundwater vulnerability. Hence, the central part of the OAU campus with high gradient that provides less opportunity for contaminant infiltration was considered as having low groundwater vulnerability potential. The flanks of the OAU campus with lower gradient of < 1° would experience higher groundwater recharge with higher groundwater vulnerability (Fig. 5). Hence, these areas with gradients that provide greater opportunity for contaminant infiltration were considered as having higher groundwater vulnerability potential.

Thickness of Weathered Layer

The thickness of the weathered materials which is the overburden thickness overlying the bedrock was contoured to generate the isopach map of the OAU campus (Fig. 6). The overburden thicknesses obtained for this study varied between 0 m and 84.3 m. The wide range of overburden thickness translates to varied depths to fresh basement within the study area, resulting from the differential weathering of the different basement rocks.

The isopach map revealed graduation in overburden thickness from thin overburden of less than 5.0 m around the central part of the OAU campus, underlain by granite gneiss to thick overburden of about 84.3 m above the mica schist, located towards the flanks of the OAU campus. The granite gneiss exists mostly as an outcrop in the central part of the OAU campus. This highly resistant granite gneiss is responsible for the thin overburden materials observed in the central part of the OAU campus. The maximum depth to fresh basement of 84.3 m occurred beneath VES 27 within the mica schist in the western flank of the study area (Fig. 2).

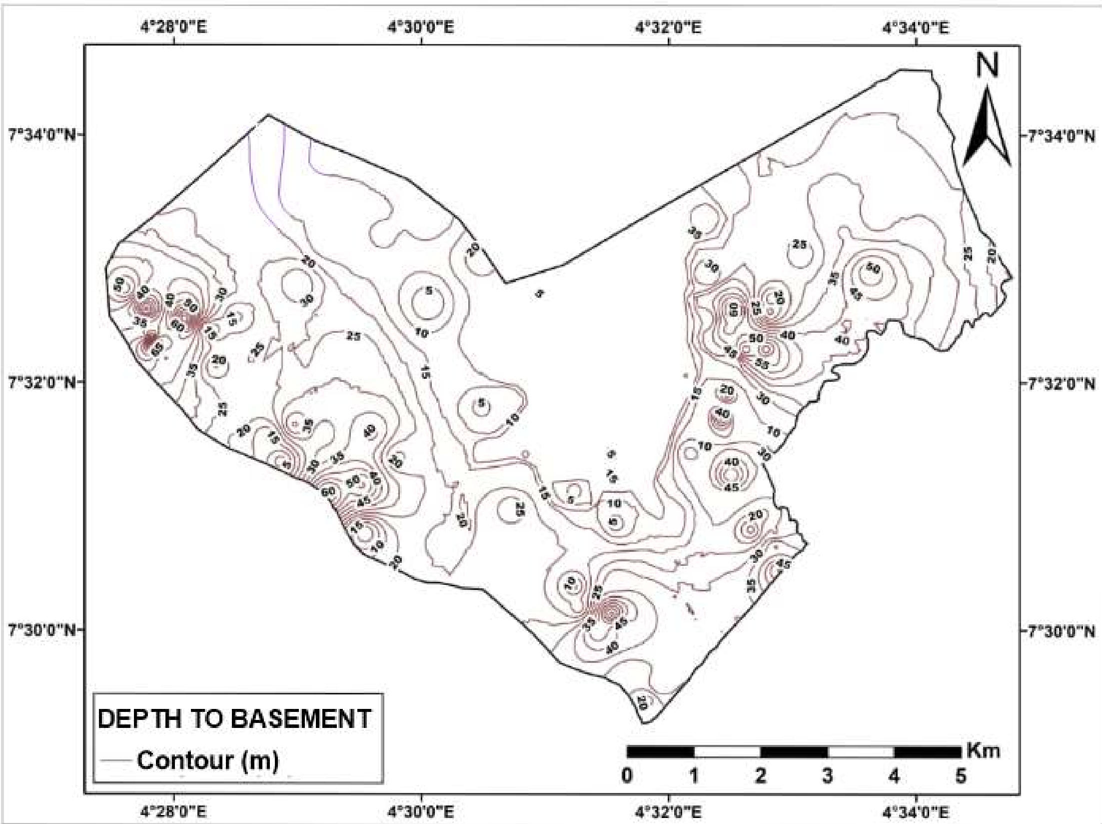

Figure 6: Isopach Map of OAU Campus

Groundwater flow mimics basement topography, hence, groundwater usually flows from shallow to deeper basement topographic areas (Asiwaju-Bello *et al*., 2020; Konwea, 2021). Thick overburden thickness indicates larger depth to fresh basement, resulting in longer groundwater path length with greater pollutant attenuation effect. Thin overburden thickness indicates smaller depth to fresh basement, resulting in shorter groundwater path length with lesser pollutant attenuation effect. Therefore, groundwater vulnerability increases with decrease in overburden thickness.

Based on thickness of weathered material, the northwestern, western, and eastern parts of the OAU campus with thicker overburden were considered as having low groundwater pollution potential because of the longer pollutant path length. The central and southwestern parts of the OAU campus with thinner overburden were considered as having high groundwater pollution potential because of the shorter pollutant path length.

Weight Assignment and Normalization for Groundwater Vulnerability Potential

The hydrogeological parameters influencing groundwater vulnerability of the OAU campus used in this study include geology, lineament, slope gradient and thickness of weathered layer. These parameters influence groundwater vulnerability to varying degrees and are interdependent (Figure 7).

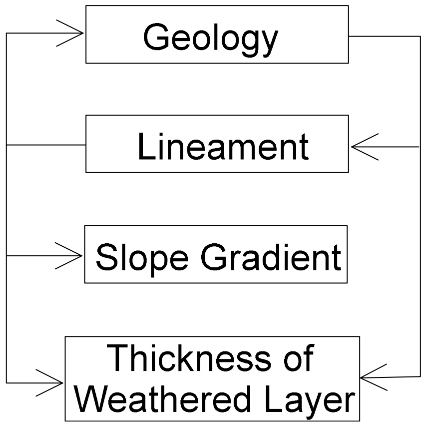

Figure 7: Interdependence of Different Hydrogeological Parameters

Interrelationship between two factors was assigned a weight of 2.0 units. Also, when no interrelationship existed between two factors, a weight of 1.0 unit was assigned. Hence, the total weight unit of each parameter represents the weight of its vulnerability. The evaluated weight of all the factors on the groundwater vulnerability of OAU campus was determined from the interrelationship among the parameters (Table 1). The results revealed that the factors influencing groundwater vulnerability of the OAU campus, in decreasing order, were lineament, geology, slope gradient and thickness of weathered layer

Table 1: Relative Rate and Percentage Weight of Groundwater Potential Factor

S/No	Factor	Procedure for calculation	Relative Rate	% Weight (*W*)
1	Geology	(4 x 1.0)	4	33.4
2	Lineament	(6 x 1.0)	6	50
3	Slope gradient	(1 x 1.0)	1	8.3
4	Thickness of weathered layer	(1 x 1.0)	1	8.3

Generation of Groundwater Vulnerability Map

The DRASTIC Index (DI), which is the sum of the effects of the four (4) parameters of geology, lineament, slope gradient and thickness of weathered layer indicates the degree of groundwater vulnerability. The DI was computed for each parameter using Equation 1.

$$DI = \sum(W_i \times R_i) \qquad 1$$

where:
W_i = weight coefficient for parameter i
R_i = rating value for parameter i

A high DI implies high groundwater vulnerability while low DI implies low groundwater vulnerability (Aller *et al.*, 1987). The DRASTIC rating values for the various parameters are shown in Table 2.

Table 2: DRASTIC Rating Values for various Hydrogeological Conditions

S/N	Thematic map (Layer)	Attribute	Rating (*R*)	Ground-water Vul-nerability	Weight (*W*)	DRASTIC Index (*WxR)*
1	Lineament	A	3	High	50	150
		B	2	Moderate		100
		C	1	Low		50
2	Geology	Gneiss and Migmatite Undifferentiated	1	Low	33.4	33.4
		Granite Gneiss	2	Low		66.8
		Banded Gneiss	2	Low		66.8
		Schist Undifferentiated	3	Moderate		100.2
		Pegmatite	4	High		133.6
3	Thickness of weathered zone	> 20	1	Low	8.3	24.9
		10 – 20	2	Moderate		16.6
		< 10	3	High		24.9
4	Slope Gradi-ent	0 – 1.0	3	High	8.3	24.9
		1.0 – 3.0	2	Moderate		16.6
		>3.0	1	Low		8.3

Three classes of vulnerability ranking were selected to describe the relative assessment of the probability of groundwater resources of OAU campus to contamination. They are High, Moderate and Low (Fig. 8). Each of the classes was indicated with a distinct colour on the vulnerability map.

Two percent (2%) of the OAU campus has high vulnerability and is shown in red, 8% of the OAU campus has moderate vulnerability and is shown in yellow, while 90% of the OAU campus has low vulnerability and is shown in green.

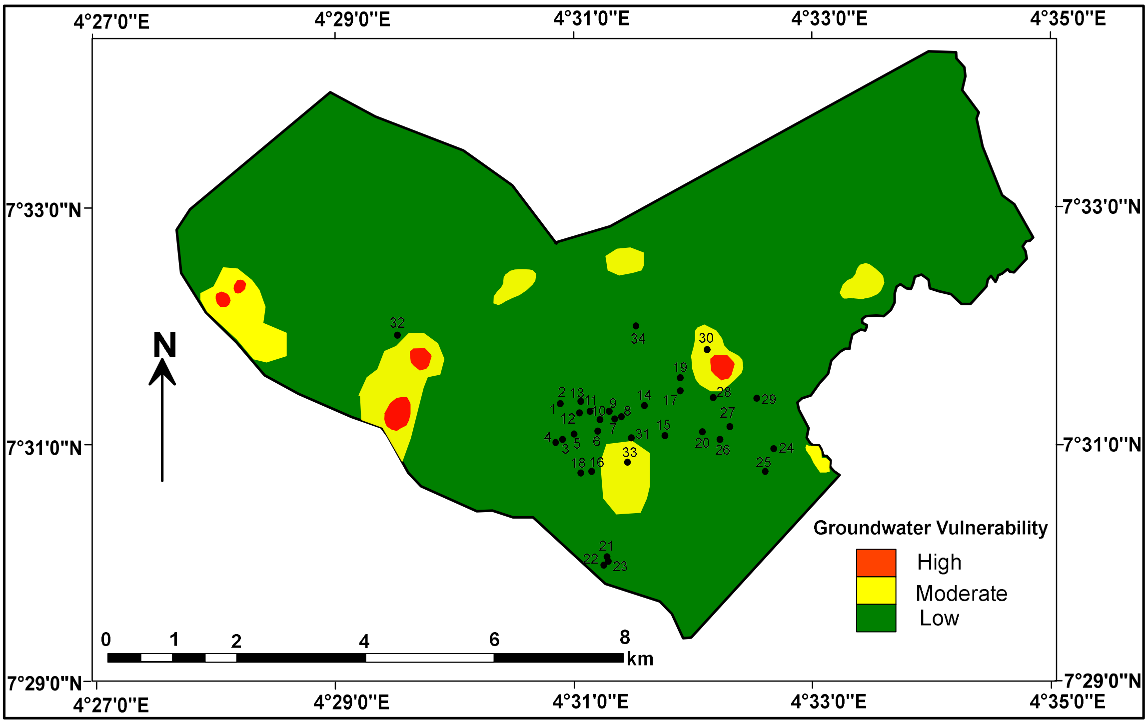

Figure 8: Groundwater Vulnerability Map of OAU Campus

Suitability Assessment of Waste Dump Locations within OAU Campus

The solid waste materials generated within the OAU campus consist of paper, plastic, wood, food items, cloth, glass, and metal. Figure 8 shows the locations where these waste materials are deposited. Some of the waste materials are deposited at authorised locations within the campus, while others have been dumped indiscriminately. The improper disposal of wastes at authorised and unauthorised locations and the infrequent collection of such wastes have resulted in poor waste management system within the OAU campus. Poor waste management practice has serious implications for water quality as the leachates from such wastes ultimately find their way into surface water and groundwater systems, thereby impairing water quality.

The areas identified as High vulnerability are the least predominant within the OAU campus and occurred mainly as small patches in the central and southwestern parts of the OAU campus underlain by gneisses. A small patch of High vulnerability ranked region occurs west of the campus within the mica schist. There is no waste dump located within the High vulnerability ranked groundwater resources region (Fig. 8).

The groundwater region ranked as Moderate vulnerability occurred mostly as patches in the central, eastern, and western parts of the OAU campus. The few patches of the High and Moderate vulnerability regions indicate that the hydrogeological parameters influencing groundwater vulnerability within the campus are not prevalent. There are two (2) waste dump sites located within the Moderate vulnerability ranked groundwater resources region. These are waste dumps 30 and 33, located in the Senior Staff Quarters and behind the Access Bank building, respectively.

The groundwater region ranked as Low vulnerability is the most predominant region within the OAU campus. All the waste dump locations within the OAU campus are situated within this region, except for waste dump locations 30 and 33. The high clayey content of the topsoil material and its low permeability make this region less vulnerable to groundwater contamination. Although the basement rocks have near surface lineaments, the clayey weathered material overlying the fresh basement rock makes good filter materials, hence giving the region high overburden protection capacity. This area is the most suitable for siting waste dumps within the OAU campus.

Although most of the regions ranked Low vulnerability have thick clayey topsoil and low permeability making the groundwater relatively safe, care should be taken in the development of these areas to avoid the removal of the topsoil through excavation and increasing permeability through boring of open holes. These processes would increase the vulnerability of the groundwater within the region.

CONCLUSIONS

The groundwater vulnerability assessment of OAU campus using the modified DRASTIC technique revealed that the area is subdivided into High (2%), Moderate (8%) and Low (90%) groundwater vulnerability regions. The Low groundwater vulnerability region is the most predominant based on the prevailing hydrogeological conditions of geology, lineament density, slope, and thickness of weathered layer. The Low groundwater vulnerability region is the most suitable for locating waste dumps within the OAU campus. Most of the waste dumps are well situated within this Low groundwater vulnerability region. Care should be taken in the development of the waste dump location to avoid the reduction or complete removal of the topsoil through excavation; or increasing the permeability of the area through boring of open holes. These processes would increase the vulnerability of groundwater resources to pollution within the region.

REFERENCES

Abdullahi, B.U., Rai J.K., Momoh, M. and Udensi, E.E. (2013). Effects of Lineament on Groundwater Occurrence. International Journal of Environment and Bioenergy 8 (1): 22 – 32.

Adejuwon, J.O. and Mbuk, C.J. (2011). Biological and Physiochemical Properties of Shallow Wells in Ikorodu Town, Lagos, Nigeria. Journal of Geology and Mining Research 3 (6): 161 – 168. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.1014.496&rep=rep1&type=pdf

Adepelumi, A., Ako, B. and Ajayi, T. (2001). Groundwater contamination in the basement-complex area of Ile-Ife, southwestern Nigeria: A case study using the electrical-resistivity geophysical method. Hydrogeology Journal 9: 611–622. https://doi.org/10.1007/s10040-001-0160-x

Ajani, O.O., Adagunodo, T.A., Adeniji, A.A., Fashae, B., Omeje, M. and Adewoyin, O.O. (2020). Investigation of groundwater contamination from leachate migration: a case study of Bowen University dumpsite, Nigeria. 4th International Conference on Science and Sustainable Development (ICSSD 2020), IOP Conf. Series: Earth and Environmental Science. doi:10.1088/1755-1315/655/1/012069

Ajayi, O. and Abegunrin, O.O. (1990). Causes of Borehole Failures in Crystalline Rocks of South-western Nigeria. In: Proceedings of the 1st Biennial National Hydrology Symposium, Maiduguri, Nigeria. Published by UNESCO, pp. 466 – 490.

Ajayi, O., Konwea, C.I. and Alimi, J.A. (2020). Groundwater Occurrence and Development in the Daura Area of Katsina State, Extreme Northern Nigeria. International Journal of Geography and Geology, Vol. 10 (1): 9 – 23.

Akinfaderin, T.D., Asiwaju-Bello, Y.A. and Ogunsuyi, M.T. (2019). Hydrochemical Characterization and Vulnerability Assessment of Unconfined Groundwater System in Ore Area, Southwestern Nigeria. SN Appl. Sci. 1, 534. https://doi.org/10.1007/S42452-019-0458-8.

Akinluyi, F.O., Olorunfemi, M.O. and Bayowa, O.G. (2021). Application of Remote Sensing, GIS and Geophysical Techniques for Groundwater Potential Development in the Crystalline Basement Complex of Ondo State, Southwestern Nigeria. Sustainable Water Resources Management. DOI. Org/10.1007/s40899-020-00486-5.

Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hackett, G. (1987). DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings. USEPA Report 600/287/035, U.S. Environmental Protection Agency.

Amuda, O.S. and Alade, A. (2006). Coagulation/Flocculation Process in the Treatment of Abattoir Wastewater. Elsevier: 22 – 31.

Asiwaju-Bello, Y.A., Olabode, O.F. and Ogunsuyi, M.T. (2020). Pollution potential and causative hydrogeochemical processes in unconfined aquifer systems in a typical urban setting: emphasis on recharge and discharge areas. Applied Water Science (2020) 10:52 https://doi.org/10.1007/s13201-019-1131-5

Ayoade, J.O. (1975). Water Resources and their Development in Nigeria. Hydrological Sciences Bulletin 20 (4): 581 – 591.

Bayowa, G.O., Falebita, D.E., Olorunfemi, M.O. and Adepelumi, A.A. (2012). Groundwater Contamination Prediction Using Finite Element Derived Geoelectric Parameters Constrained by Chemical Analysis around a Sewage Site, Southwestern Nigeria. International Journal of Geosciences 3: 404 – 409.

Bayowa, G.O., Olorunfemi, M.O., Akinluyi, F.O. and Ademilua, L.O. (2014). A Further Comprehensive Approach to Assessing the Groundwater Potential of the Basement Complex Terrain of Ekiti State, Southwestern Nigeria. International Journal of Scientific and Technology Research 3 (7): 35 – 46.

Bilardi, S., Ielo, D. and Moraci, N. (2020). Predicting the Saturated Hydraulic Conductivity of Clayey Soils and Clayey or Silty Sands. Geosciences 10: 393. doi:10.3390/geosciences10100393

Cobbina, S.J., Nsonwah, E., Duwiejuah, A.B. and Nkoom, M. (2014). Assessment of Trace Metals in Soil at the Bulk Oil Storage and Transportation (BOST) Facility in Buipe, Ghana. Research Journal of Chemical and Environmental Sciences l 2: 40 – 47.

Edet, A.E., Teme, S.C., Okereke, C.S. and Esu, E.O. (1998). Application of remote sensing data to groundwater exploration: A case study of the Cross River State, Southeastern Nigeria. Hydrogeol. J. 6: 394 – 404.

Foster, S.S.D., Hirata, R.C.A., Gomes, D, Delia, M., and Paris M. (2002). Quality Protection Groundwater: Guide for Water Service Companies, Municipal Authorities and Environment Agencies. World Bank, Washington DC. https://doi.org/10.1596/0-8213-4951-1.

Ganiyu, S.A., Badmus, B.S., Oladunjoye, M.A., Aizebeokhai, A.P., Ozebo, V.C., Idowu, O.A. and Olurin, O.T. (2016). Assessment of groundwater contamination around active dumpsite in Ibadan southwestern Nigeria using integrated electrical resistivity and hydrochemical methods. Environmental Earth Science. DOI 10.1007/s12665-016-5463-2.

Gennaro, P. (2001). Groundwater Vulnerability Map Explanatory Notes. Centre for Natural Resources, NSW Department of Land and Water Conservation, Parramatta. 18 pp.

Grinevsky, S.O. (2014). Effect of Topography on the Formation of Groundwater Recharge. Moscow University Geology Bulletin 69 (1): 47 – 52. DOI: 10.3103/S0145875214010025.

Ighalo, J.O. and Adeniyi, A.G. (2020). A comprehensive review of water quality monitoring and assessment in Nigeria. Chemosphere 260. https://doi.org/10.1016/j.chemosphere.2020.127569

Jaseela, C, Prabhakar, K. and Harikumar, P. (2016). Application of GIS and DRASTIC Modelling for Evaluation of Groundwater Vulnerability near a Solid Waste Disposal Site. International Journal of Geosciences 7: 558 – 571. Doi: 10.4236/ijg.2016.74043.

Joe-Ukairo, A. and Oni, A.G. (2018). Geophysical and hydro-chemical investigations of Oke Asunle dumpsite in Ile-Ife, Southwestern Nigeria for subsoil and surface water pollution. Journal of Health and Pollution 8(20): 181 – 209.

Konwea, C.I., Ajayi, O. and Salami, B.M. (2021). Integrated Geophysical and Hydrogeological Assessment of the Groundwater Resources of Obafemi Awolowo University Campus, Southwestern Nigeria. In: Proceedings of the 56th Annual International Conference and Exhibitions of the Nigerian Mining and Geosciences Society (NMGS), pp. 111 - 116.

Konwea, C.I. (2021). Hydrogeological and Hydrogeophysical Appraisal of the Groundwater Resources of Obafemi Awolowo University Estate, Ile-Ife, Southwestern Nigeria. Unpublished Ph. D. Thesis, Department of Geology, Obafemi Awolowo University.

Konwea, C.I., Evurani, D.E., Ajayi, O. (2023). Assessment of Groundwater Potential of the Obafemi Awolowo University Estate, Southwestern Nigeria. Scientific African, https://doi.org/10.1016/j.sciaf.2023.e01597

Mogaji, K.A., Aboyeji, O.S. and Omosuyi, G.O. (2011). Mapping of lineaments for groundwater targeting in the basement complex region of Ondo State, Nigeria, using remote sensing and geographic information system (GIS) techniques. International Journal of Water Resources and Environmental Engineering 3 (7): 150 – 160. Available online at http://www.academicjournals.org/ijwree

Nevondo, V., Malehase, T., Daso, A.P. and Okonkwo, O.J. (2019). Leachate seepage from landfill: a source of groundwater mercury contamination in South Africa. Water SA, Vol, 45 (2). DOI: 10.4314/wsa. v45i2.09

Obase, K.O., Olorunfemi, M.O. and Akintorinwa, J.O. (2009). Geophysical and Hydrochemical Investigation of the Area around a Waste Dump Site in Ile-Ife, Southwest Nigeria. Global Journal of Geological Sciences 7 (1): 47 – 54.

Olorunfemi, M.O., Oni, A.G., Bamidele, O.E., Fadare, T.K. and Aniko, O.O.

(2020). Combined Geophysical Investigations of the Characteristics of a Regional Zone for Groundwater Development in a Basement Complex Terrain of South-west Nigeria. Springer Nature. http://doi.org/10.1007/S424452-020-2363-6.

Oni, T.E., Omosuyi, G.O. and Akinlalu, A.A. (2017). Groundwater Vulnerability Assessment using Hydrogeologic and Geoelectric layer Susceptibility Indexing at Ibara Oke, Southwestern Nigeria. NRIAG Journal of Astronomy and Geophysics 6 (2): 452 – 458. https://doi.org/10.1016/j.nrjag.2017.04.009.

Oyedele, D.J., Gasu, M.B. and Awotoye, O.O. (2008). Change in Soil Properties and Plant Uptake of Heavy Metals on elected Municipal Waste Dump Sites in Ile-Ife, Nigeria. African Journal of Environmental Science and Technology 3 (5): 107 – 115.

Ozbek, A., Gul, M., Karacan, E. and Alca, O. (2018). Anisotropy effect on strengths of metamorphic rocks. Journal of Rock Mechanics and Geotechnical Engineering 10 (1): 164 – 175. https://doi.org/10.1016/j.jrmge.2017.09.006

Plunder, A., Pourhiet, L.L., Räss, L., Gloaguen, E., Pichavant, M. and Gumiaux, C. (2022). Pegmatites as geological expressions of spontaneous crustal flow localisation. Lithos 416 – 417. https://doi.org/10.1016/j.lithos.2022.106652

Sarikhani, R., Kamali, Z. and Dehnavi, A.G. (2014). Correlation of lineaments and groundwater quality in Dasht-e-Arjan Fars, SW of Iran. Environmental Earth Sciences 72 (7): 2369 – 2387. DOI:10.1007/s12665-014-3146-4

Shahzad, F., Mahmood, S.A. and Gloaguen, R. (2009). Drainage Network and Lineament Analysis: An Approach for Potwar Plateau (Northern Pakistan). J. Mt. Sci. 9: 14 – 24. DOI:10.1007/S11629-009-0206-4.

Tijani, M.N., Onibalusi, S.O. and Olatunji, A.S. (2002). Hydrochemical and Environmental Impact Assessment of Orita Aperin Waste Dumpsite, South-western Nigeria. Waste Resources Journal 13: 78 – 85.

Todd, D.K. and Mays, L.W. (2005). Groundwater Hydrology. Third Edition, John Wiley, and Sons Inc. 624 pp.

UN WWAP, (2003). United Nations World Water Assessment Programme. The World Water Development Report 1 Water for People, Water for Life. UNESCO, Paris.

World Health Organization (WHO), (2015). Guidelines for Drinking water Quality. Final Task Group Meeting; WHO: Geneva, Switzerland.

Mustapha, A. and Getso, B.U. (2014). Sources and pathway of Environmental Pollutants into Surface Water Resources: A Review. Journal of Environments 1 (2): 54 – 59.