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Ground Water Contamination: Effects and Remedies

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Authors' contributions

This work was carried out in collaboration among all authors. Authors JMH, DIO and RUH designed the study, while authors RUH, JMH, YAO and MHH did the statistical analysis. The protocol was written by authors JMH, AFA and YAO. The first draft of the manuscript was written by authors JMH, DIO, YAO and MHH. Analysis of the study and literature searches was done by authors JMH, RUH, DIO, YAO, AFA and MHH. All the authors read and approved the final manuscript.

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ABSTRACT

Studies on "ground water contamination : effects and remedies" have been conducted, in the light of these, field work studies in Obudu and Obanliku local Government Areas of Cross River State, South Eastern Nigeria, was conducted. Fifteen (15) locations of water for drinking and other domestic uses were carefully studied in the area, with their surface to water depth values recorded. Five(5) of the locations were at surface saturated water depressions(SWD), seven(7) were Hand dug wells(well), while three(3) were bore holes(BH). The physiochemical composition data compared with world Health Organization (WHO) standard shows that, the bore water was safer for drinking than the hand dug wells and surface water in saturated water depressions. Coliform count unite per 100ml of water, were detected in most of the locations in the saturated water depressions

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and hand dug wells, showing evidence of biogenic interference with the water. Coliform count unite per 100ml of water was not detected in any of the three bore holes, probably due to their depth distance from Biogenic activities. Phosphate and Nitrate levels were significantly above WHO standard in saturated water depressions and Hand dug wells, probably due to erosional and leaching actions of inorganic fertilizers from farm lands and waste from near dump site. It is important to note that most water borne diseases are as a result of ground water communication with contaminant, such as heavy metals, leachate from dump sites, pollutants from inorganic fertilizers, pith toilets sea water intrusion etc., most boreholes are contaminated by these processes. This is one of the reasons for the increase in the rate of cancer in most developing countries. Hence, heavy metals are known to be carcinogenic to the human cells, and also can cause mutation. The remedies to these include:

- The process of exploiting and storing ground water should be done with all safety precautions, such as making sure biochemical parameters in water are in line with WHO standard
- Thorough biochemical analysis and test for the presence of heavy metal contamination and coliform count and other contaminants should be done on ground water, before use for domestic and industrial purposes.
- Surface depth measurement of recharge zones in boreholes should be carried out to ensure that borehole water is from confined aquifers that are safe for domestic and industrial uses.
- Proper waste disposing system such as engineered toilet pits, engineered dump sites and effective management of electronic waste should be monitored and implemented
- Where the purity of the water is not satisfactory, such water should be properly treated before used for drinking and other domestic purposes.

Keywords: Biogenic; dump site; aquifers; leachate actions; carcinogenic; heavy metals; intrusion.

1. INTRODUCTION

The importance of water in the lives of humans, plants, and animals cannot be overemphasized because of its vital role. Ground water is one way of accessing water for domestic and industrial uses. Unfortunately, natural and human activities such as agriculture, exploration and exploitation of hydrocarbon, construction, poor waste management System, natural dissolution of heavy metals in ground tectonic activities and sea intrusion, have contributed to ground water contamination. According to Benjamin [1], groundwater is an essential natural resource in most places, and it makes up about 30% of the world's freshwater reserve. Similarly, the United Nations [2], noted that fresh water is a precious resource that is essential to human health, food and energy security, poverty eradication and many other aspects of sustainable development. Water-related ecosystems have always provided natural sites for human settlements. Half of the world's population is already experiencing severe water scarcity at least one month a year. The United State Geological Society [3], further noted that about 33% of the water that most Countries and Cities Water Department supply to households and businesses, is from ground water, which also serves as drinking water for about 90% of the rural population who do not get their water delivered to them from a Country/City Department. According to Pawari & Gawade [4], the effects of ground water pollution are high, and worldwide infectious diseases such as waterborne diseases are the number one killer of children under five (5) years old, and more people die from unsafe water annually than from all forms of violence. In rural areas in Nigeria for example, ground water is the major source of drinking water and for domestic uses. Some persons access their ground water from very shallow bore holes or valleys with erosional exposed water tables. Lateral and vertical heterogeneities in soil strata including leachate and erosional wash of heavy metals have deposited harmful materials into ground water. The ignorance of human activities have dangerously contaminated ground water in so many ways, such as poor or no engineering dump site, improper electronic waste disposing system, establishment of pit toilet without considering ground water contamination, etc. Contaminated water can transmit diseases such as diarrhea, cholera, dysentery, typhoid, and polio. The research work identifies some of the possible ways in which ground water has been contaminated by human and natural occurrences, such as, tectonic, sea water intrusion, diaperic salt intrusion, uplift and subsidence, etc. As a remedial measure to ground water contamination, thorough investigation of the area of which the ground water is gotten has to be made, to guarantee the safety of the ground water including adequate water test and analysis. Bore hole water with all the safety measures is one good source of ground water due to distances away from the earth surface and biogenic activities. Most hand dug wells are poorly located, disregarding the impact of soakaways on ground water. There is a need for hand dug wells to be located at safe distances and at depth at least above 5 meters. The government of every nation should be interested on the sources of water for its citizens, and meaningful percentage of its budgetary allocations be allocated to water to guarantee the safety of the people.

1.1 Objectives

i. To investigate how ground water can be contaminated
ii. To highlight possible subsurface geometries and orientation of aquifers and how it affect ground water purity
iii. To identify aquifers and their defects
iv. To highlight how human activities affect the purity of ground water, and the likely diseases associated with contaminated ground water
v. To provide remedies to ground water contamination.

1.2 Area of the Study

The study area (Obudu and Obanliku Local Government Areas of Cross River State, Nigeria) is situated within the Niger Delta region in the tropical rain forest belt. It lies between latitude 5°32^1 and 4°27^1 North and longitude 7°50^1 and 9°28^1 East, with temperature ranging between 15°c – 30°c and annual rainfall between 1300 – 3000mm [5].

1.3 Scope of the Study

The work is limited to the possible ways of ground water contamination, effects and remedies.

2. GROUND WATER CONTAMINATION PATHWAYS

According to Benjamin [1], groundwater in time past was known to be clean and free from contamination, however, due to rapid industrialization and increased use of chemicals, numerous contaminants often find their way into the groundwater. The significant sources of contamination in groundwater are farming chemicals, septic waste, landfills, uncontrolled hazardous waste, storage tanks, atmospheric pollutants, etc:

i. Agricultural Activities: The increase in agricultural activities to meet the rapidly growing human population has prompted the increase use of farm chemicals such as pesticides, herbicides, and fertilizers. These chemicals used on farms settle on the ground, and when it rains, they mix with the rainwater and seep through the porous ground to reach the underground water, thereby contaminating the ground water that was originally pure.

ii. Septic Waste: Septic waste contributes greatly to ground water pollution. Hence, it is essential that such waste is treated before disposal. Treatment prevents harmful substances from getting into the ground and spreading to the water. Additionally, the septic systems are structured to confine the waste. However, poorly designed septic systems release viruses, bacteria, and chemicals into the groundwater and make it unfit for human consumption. Poorly maintained septic tanks can also result to leaks which can cause groundwater contamination.

iii. Poor Waste Management System: The increase in human population has also led to the increase in garbage. This garbage collected is most times taken to particular locations known as landfills where there are buried. Landfills ideally are required to have a protective layer at the bottom to stop the waste from seeping into the ground. Unfortunately, some landfills lack that protective layer, and in some cases, the layer is faulty. Such landfills result in leaks of contaminants such as chemicals, car battery acid, oil, and medical products into the groundwater and get it contaminated. Also, most electronic waste are not properly managed, some of which are radioactive. Human waste in pit toilets with faulty engineering structures can make contacts with ground water and sediments. In most areas, the water table is very low, making ground water contamination easy.

iv. The Use of Storage Tanks: Chemicals, oil, minerals, and other products are often kept in storage tanks above or below the ground. In the United States alone for example, it is estimated that more than 10 million storage barrels containing different substances are stored underground. Over time, the storage containers erode, and this may result in harmful substances leaking into the ground. Subsequently, the contaminants move through the soil and reach the groundwater making it unfit for human use [1].

v. The Use of Underground Pipes: Although there are different ways of transporting products, the use of underground pipes is common. Products such as oil, farm chemicals, cooking gas, and drinking water are mainly transported through underground pipes. In many instances, the underground pipes burst and release their content into the ground. These incidents often lead to groundwater contamination.

vi. The Use of Road Salts and Diaperic Intrusions into Ground Water: Road salts are mainly used in places that have snowfall during winter. Road salts are chemical products used to melt ice on the road. Once the ice melts, it flows with the chemicals to into the ground thereby contaminating the ground water. And due to the density contrast of salt and the surrounding environment, natural salts deposits are driven off, and in the process are deposited in aquifers and ground water due to their up-thrust, thereby contaminating the ground water [6].

vii. Mining Activities: Most mineral deposit with depths, interfere with aquifers and streams and there are contaminated with heavy metals in the process. Either these metals are consumed directly by man and animals or indirectly through capillary actions, most plants useful to man take in these metals through their root system. And these heavy metals have been known to cause different kinds of sicknesses including cancer in man.

viii. Tectonic Occurrences: Tectonic occurrences such as landslides, earthquake, uplifts, rifting, etc, can also get ground water contaminated.

ix. Hydrocarbon Exploration and Exploitation: During hydrocarbon exploration and exploitation, ground water, ponds, rivers, and land are heavily contaminated due to oil spills during exploitation and transportation challenges. The Picture bellow is an example of oil spill leading to ground water pollution:

x. Sea Water Intrusion: Sea water intrusion has contributed greatly to ground water contamination in some areas, either due to uplift, subsidence, convergence, divergence, strike slip tectonic deformation episodes, and other transgrasive activities.

3. AQUIFERS

An aquifer is a body of porous rock or sediment saturated with ground water. Ground water enters an aquifer as precipitation seeps through the soil. It can move through the aquifer and resurface springs and wells [National Geographic Society, "Aquifer," in www.nationalgeographic.org. Accessed 29/10/2020) [7].

There are basically two types of aquifers: Confined and unconfined aquifers. However, others include perched aquifers, artesian aquifers, etc. [8]

a. **Confined Aquifer:** This is an aquifer that the four-way closure is guided by impermeable layer, and it is free from contaminants.
b. **Unconfined Aquifer:** This is an aquifer that is saturated by with water and guided with permeable layer of sediments.
c. **Perched Aquifer Semi-Confined Aquifer:** This is an aquifer that is not 100% guided by impermeable layer. There is a partial interference of external water due to partial permeability of the guided layer.
d. **Artesian Aquifer:** This is a confined aquifer with very high positive pressure [5]. If a well is established in an artesian aquifer, the water level will rise to a height until the hydrostatic equilibrium is attained. Artesian aquifer for example has been identified in Agbumana Ezeagu Local Government Area of Enugu State, Nigeria.

4. GEOMETRIES AND DEFFECTS IN AQUIFERS

i. **Tectonics:** Most confined aquifers due to tectonic occurrences such as faulting, folding, subsidence, etc, are made to be permeable. And this can contribute to ground water contamination in the aquifer. Tectonic events such as the Pyrenees of Spain, Alps of France and Switzerland, Apennines of Northern Italy, Himalayas of India and Pakistan, and Andes of South America with tectonic history are good examples. Tectonic occurrences such as the Pan Africa Orogeny, have contributed to surface and subsurface beds not obeying the Law of Original horizontality and principle of superposition, such that with an extensive lateral extent, some boreholes with depths are still within the region of unconfined aquifers or weathered sediments, which makes the hydro dynamic system contaminated; this account for the high coliform count, heavy metal contamination, leachate contamination in some bore water.

ii. **Exploration and Exploitation Activities**: During hydrocarbon exploration and exploitation, most aquifers are penetrated, thus, destroying the original quality of water in the aquifer, and in the process, the ground water can be contaminated.

iii. Confined aquifers may have contact with pit toilets or leachates from dumped sites. And this can contribute to aquifers being contaminated by human waste and diseases causing pathogens. The topography of a particular area may not reflect subsurface orientation and geometry of beds.

5. THE EFFECTS OF GROUND WATER CONTAMINATION

a. Health Effects On:

- **Humans:** Contaminated water accounts for most of the health challenges in humans. According to the Annan [9] water related diseases kill a child every eight (8) seconds, and these diseases are responsible for 80% of all illnesses in the developing world. These water borne diseases include cholera, cancer, diarrhea, dysentery, skin diseases, poliomyelitis, worm infections, eye infections, hepatitis, etc [10].
- **Animals:** Animals in the wild depending on ground water for drinking may suffer a great deal of health challenges if the ground water within their reach is contaminated. Most aquatic animals within the Niger Delta Region of Nigeria, for example have gone into extinction due to hydrocarbon exploration and exploitation. Eutrophication has been reported in most areas in Nigeria due to the application of inorganic fertilizers, which has contaminated ground water. NPK fertilizers for example are known to increase the colonies of algae, algae are known to deplete the oxygen content in water, thus reducing Biological Oxygen Demand (BOD) of the water, in which case the water is polluted.
- **Plants:** Ground water contamination has a wide variety of effects on plants life and the environment in general. Pollution in water does not only harm plants growth but also allows plants to absorb dangerious chemicals from the water and pass them on to humans and animals that depend on them for survival [11], and when man consumes these plants, he indirectly consumes the heavy metals, thereby causing numerous health challenges such as liver failure, kidney failure, cancer, etc.

b. Economic and Environmental Effects: Industries relying on ground water for their uses may face series of challenges due to ground water contamination, in which case, their cost of production may increase or totally shot down, since they have to outsource uncontaminated water for operation. Ground water pollution can lead to devastating environmental changes in the ecosystem, such as the loss of certain nutrients essential for self-sustenance. It is also important to note that in an ecosystem, plants are the primary producers in the food chain. When aquatic environment is contaminated for example, the aquatic animals may go into extinction.

Fig. 1. Example of oil spill
Source: Benjamin Elisha Bawe [1]

Table 1. Inorganic contaminants found in ground water [12]

S/n	Contaminants	Source to ground water	Potential health and other effects
1	Aluminum	Occurs naturally in some rocks and drainage from mines.	Can precipitate out of water after treatment, causing increased turbidity or discolored water.
2	Antimony	Enters environment from natural weathering, industrial production, municipal waste disposal, and manufacturing of flame retardants, ceramics, glass, batteries, fireworks, and explosives.	Decreases longevity, alters blood levels of glucose and cholesterol in laboratory animals exposed at high levels over their lifetime.
3	Arsenic	Enters environment from natural processes, industrial activities, pesticides, and industrial waste, smelting of copper, lead, and zinc ore.	Causes acute and chronic toxicity, liver and kidney damage; decreases blood hemoglobin. A carcinogen.
4	Barium	Occurs naturally in some limestones, sandstones, and soils in the eastern United States.	Can cause a variety of cardiac, gastrointestinal, and neuromuscular effects. Associated with hypertension and cardiotoxicity in animals.
5	Beryllium	Occurs naturally in soils, groundwater, and surface water. Often used in electrical industry equipment and components, nuclear power and space industry. Enters the environment from mining operations, processing plants, and improper waste disposal. Found in low concentrations in rocks, coal, and petroleum and enters the ground.	Causes acute and chronic toxicity; can cause damage to lungs and bones. Possible carcinogen.
6	Cadmium	Found in low concentrations in rocks, coal, and petroleum and enters the groundwater and surface water when dissolved by acidic waters. May enter the environment from industrial discharge, mining waste, metal plating, water pipes, batteries, paints and pigments, plastic stabilizers, and landfill leachate.	Replaces zinc biochemically in the body and causes high blood pressure, liver and kidney damage, and anemia. Destroys testicular tissue and red blood cells. Toxic to aquatic biota.
7	Chloride	May be associated with the presence of sodium in drinking water when present in high concentrations. Often from saltwater intrusion, mineral dissolution, industrial and domestic waste.	Deteriorates plumbing, water heaters, and municipal water-works equipment at high levels. Above secondary maximum contaminant level, taste becomes noticeable.
8	Chromium	Enters environment from old mining operations runoff and leaching into groundwater, fossil-fuel combustion, cement-plant emissions, mineral leaching, and waste incineration. Used in metal plating and as a cooling-tower water additive.	Chromium III is a nutritionally essential element. Chromium VI is much more toxic than Chromium III and causes liver and kidney damage, internal hemorrhaging, respiratory damage, dermatitis, and ulcers on the skin at

S/n	Contaminants	Source to ground water	Potential health and other effects
			high concentrations.
9	Copper	Enters environment from metal plating, industrial and domestic waste, mining, and mineral leaching.	Can cause stomach and intestinal distress, liver and kidney damage, anemia in high doses. Imparts an adverse taste and significant staining to clothes and fixtures. Essential trace element but toxic to plants and algae at moderate levels.
10	Cyanide	Often used in electroplating, steel processing, plastics, synthetic fabrics, and fertilizer production; also from improper waste disposal.	Poisoning is the result of damage to spleen, brain, and liver.
11	Dissolved solids	Occur naturally but also enters environment from man-made sources such as landfill leachate, feedlots, or sewage. A measure of the dissolved “salts” or minerals in the water. May also include some dissolved organic compounds.	May have an influence on the acceptability of water in general. May be indicative of the presence of excess concentrations of specific substances not included in the Safe Water Drinking Act, which would make water objectionable. High concentrations of dissolved solids shorten the life of hot water heaters.
12	Fluoride	Occurs naturally or as an additive to municipal water supplies; widely used in industry.	Decreases incidence of tooth decay but high levels can stain or mottle teeth. Causes crippling bone disorder (calcification of the bones and joints) at very high levels
13	Hardness	Result of metallic ions dissolved in the water; reported as concentration of calcium carbonate. Calcium carbonate is derived from dissolved limestone or discharges from operating or abandoned mines.	Decreases the lather formation of soap and increases scale formation in hot-water heaters and low-pressure boilers at high levels.
14	Iron	Occurs naturally as a mineral from sediment and rocks or from mining, industrial waste, and corroding metal.	Imparts a bitter astringent taste to water and a brownish color to laundered clothing and plumbing fixtures.
15	Lead	Enters environment from industry, mining, plumbing, gasoline, coal, and as a water additive.	Affects red blood cell chemistry; delays normal physical and mental development in babies and young children. Causes slight deficits in attention span, hearing, and learning in children. Can cause slight increase in blood pressure in some adults. Probable carcinogen.

S/n	Contaminants	Source to ground water	Potential health and other effects
16	Manganese	Occurs naturally as a mineral from sediment and rocks or from mining and industrial waste.	Causes aesthetic and economic damage, and imparts brownish stains to laundry. Affects taste of water, and causes dark brown or black stains on plumbing fixtures. Relatively non-toxic to animals but toxic to plants at high levels.
17	Mercury	Occurs as an inorganic salt and as organic mercury compounds. Enters the environment from industrial waste, mining, pesticides, coal, electrical equipment (batteries, lamps, switches), smelting, and fossil-fuel combustion.	Causes acute and chronic toxicity. Targets the kidneys and can cause nervous system disorders.
18	Nickel	Occurs naturally in soils, groundwater, and surface water. Often used in electroplating, stainless steel and alloy products, mining, and refining.	Damages the heart and liver of laboratory animals exposed to large amounts over their lifetime.
19	Nitrate (as nitrogen)	Occurs naturally in mineral deposits, soils, seawater, freshwater systems, the atmosphere, and biota. More stable form of combined nitrogen in oxygenated water. Found in the highest levels in groundwater under extensively developed areas. Enters the environment from fertilizer, feedlots, and sewage.	Toxicity results from the body's natural breakdown of nitrate to nitrite. Causes "bluebaby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood.
20	Nitrite (combined nitrate/nitrite)	Enters environment from fertilizer, sewage, and human or farm-animal waste.	Toxicity results from the body's natural breakdown of nitrate to nitrite. Causes "bluebaby disease," or methemoglobinemia, which threatens oxygen-carrying capacity of the blood.
21	Selenium	Enters environment from naturally occurring geologic sources, sulfur, and coal.	Causes acute and chronic toxic effects in animals–"blind staggers" in cattle. Nutritionally essential element at low doses but toxic at high doses.
22	Silver	Enters environment from ore mining and processing, product fabrication, and disposal. Often used in photography, electric and electronic equipment, sterling and electroplating, alloy, and solder. Because of great economic value of silver, recovery practices are typically used to minimize loss.	Can cause argyria, a blue-gray coloration of the skin, mucous membranes, eyes, and organs in humans and animals with chronic exposure.
23	Sodium	Derived geologically from leaching of surface and underground deposits of salt and decomposition of various minerals. Human	Can be a health risk factor for those individuals on a low-sodium diet.

S/n	Contaminants	Source to ground water	Potential health and other effects
		activities contribute through de-icing and washing products.	
24	Sulfate	Elevated concentrations may result from saltwater intrusion, mineral dissolution, and domestic or industrial waste.	Forms hard scales on boilers and heat exchangers; can change the taste of water, and has a laxative effect in high doses.
25	Thallium	Enters environment from soils; used in electronics, pharmaceuticals manufacturing, glass, and alloys.	Damages kidneys, liver, brain, and intestines in laboratory animals when given in high doses over their lifetime.
26	Zinc	Found naturally in water, most frequently in areas where it is mined. Enters environment from industrial waste, metal plating, and plumbing, and is a major component of sludge.	Aids in the healing of wounds. Causes no ill health effects except in very high doses. Imparts an undesirable taste to water. Toxic to plants at high levels.

Source: Waller, Roger M [12]

Table 2. Organic contaminants found in ground water [12]

S/n	Contaminants	Sources to ground water	Potential health and other effects
1	Volatile organic compounds	Enter environment when used to make plastics, dyes, rubbers, polishes, solvents, crude oil, insecticides, inks, varnishes, paints, disinfectants, gasoline products, pharmaceuticals, preservatives, spot removers, paint removers, degreasers, and many more.	Can cause cancer and liver damage, anemia, gastrointestinal disorder, skin irritation, blurred vision, exhaustion, weight loss, damage to the nervous system, and respiratory tract irritation.
2	Pesticides	Enter environment as herbicides, insecticides, fungicides, rodenticides, and algicides	Cause poisoning, headaches, dizziness, gastrointestinal disturbance, numbness, weakness, and cancer. Destroys nervous system, thyroid, reproductive system, liver, and kidneys.
3	Plasticizers, chlorinated solvents, and dioxin	Used as sealants, linings, solvents, pesticides, plasticizers, components of gasoline, disinfectant, and wood preservative. Enters the environment from improper waste disposal, leaching runoff, leaking storage tank, and industrial runoff.	Cause cancer. Damages nervous and reproductive systems, kidney, stomach, and liver.

Source: Waller, Roger M [12]

Table 3. Microbiological contaminants found in groundwater [12]

S/n	Contaminant	Source to ground water	Potential health and other effects
1	Coliform bacteria	Occur naturally in the environment from soils and plants and in the intestines of humans and other warm-blooded animals. Used as an indicator for the presence of pathogenic bacteria, viruses, and parasites from domestic sewage, animal waste, or plant or soil material.	Bacteria, viruses, and parasites can cause polio, cholera, typhoid fever, dysentery, and infectious hepatitis.

Source: Waller, Roger M [12]

Table 4. Physical characteristics of groundwater [12]

S/n	Contaminant	Sources to groundwater	Potential health and other effects
1	Turbidity	Caused by the presence of suspended matter such as clay, silt, and fine particles of organic and inorganic matter, plankton, and other microscopic organisms. A measure how much light can filter through the water sample.	Objectionable for aesthetic reasons. Indicative of clay or other inert suspended particles in drinking water. May not adversely affect health but may cause need for additional treatment. Following rainfall, variations in groundwater turbidity may be an indicator of surface contamination.
2	Colour	Can be caused by decaying leaves, plants, organic matter, copper, iron, and manganese, which may be objectionable. Indicative of large amounts of organic chemicals, inadequate treatment, and high disinfection demand. Potential for production of excess amounts of disinfection byproducts.	Suggests that treatment is needed. No health concerns. Aesthetically unpleasing
3	P^H	Indicates, by numerical expression, the degree to which water is alkaline or acidic. Represented on a scale of 0-14 where 0 is the most acidic, 14 is the most alkaline, and 7 is neutral.	High Ph causes a bitter taste; water pipes and water-using appliances become encrusted; depresses the effectiveness of the disinfection of chlorine, thereby causing the need for additional chlorine when Ph is high. Low-Ph water will corrode or dissolve metals and other substances.
4	Odor	Certain odors may be indicative of organic or non-organic contaminants that originate from municipal or industrial waste discharges or from natural sources.	-
5	Taste	Some substances such as certain organic salts	-

S/n	Contaminant	Sources to groundwater	Potential health and other effects
		produce a taste without an odor and can be evaluated by a taste test. Many other sensations ascribed to the sense of taste actually are odors, even though the sensation is not noticed until the material is taken into the mouth.	

Source: Waller, Roger M [12]

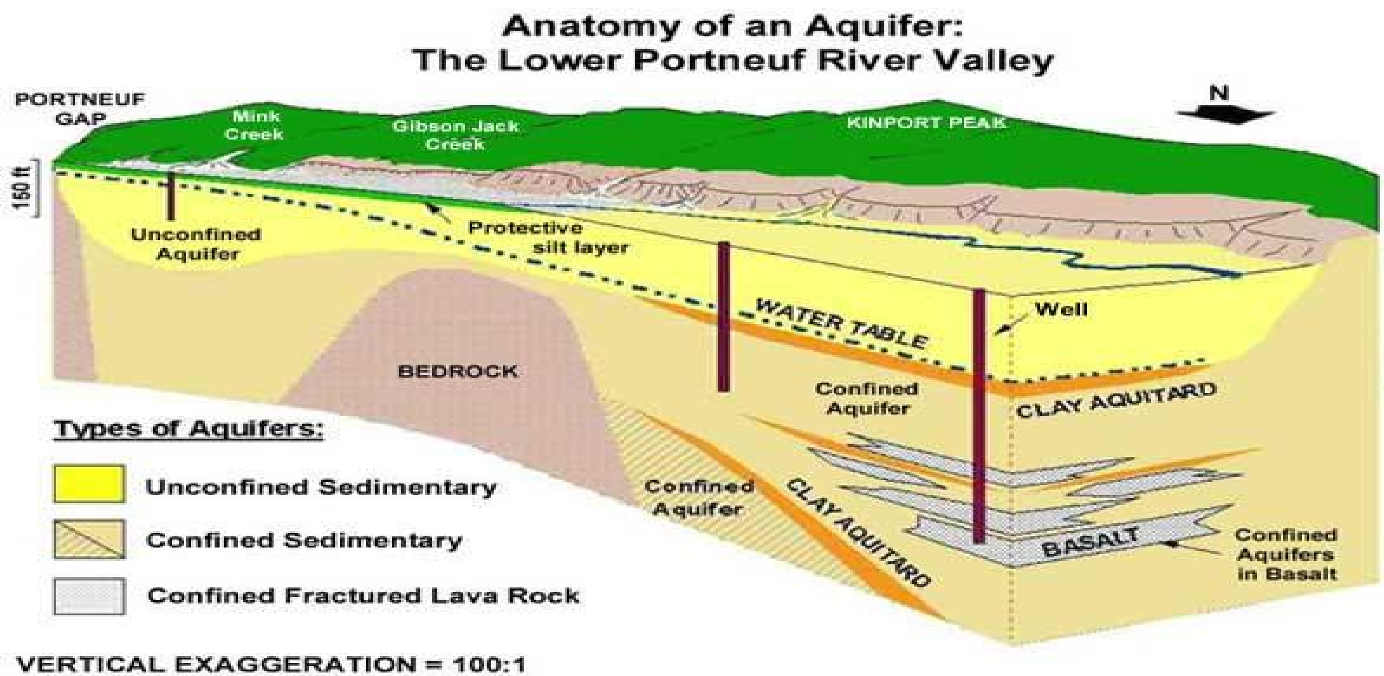

Fig. 2. Anatomy of an aquifer

Source: https://digitalatlas.cose.isu.edu/hydr/concepts/gwater/imgs/5comp.jpg [13]

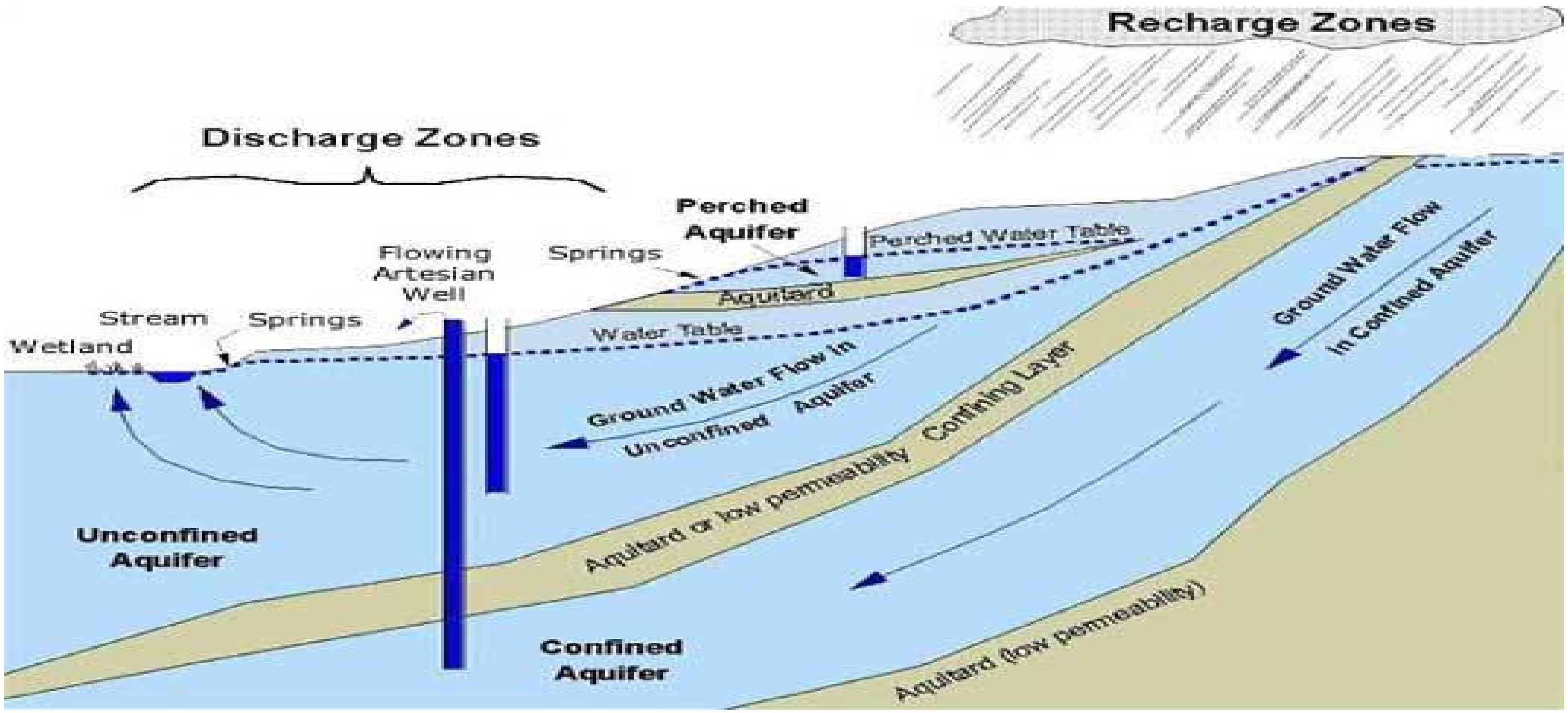

Fig. 3. Example of an aquifer
Source: https://digitalatlas.cose.isu.edu/hydr/concepts/gwater/imgs/5comp.jpg [13]

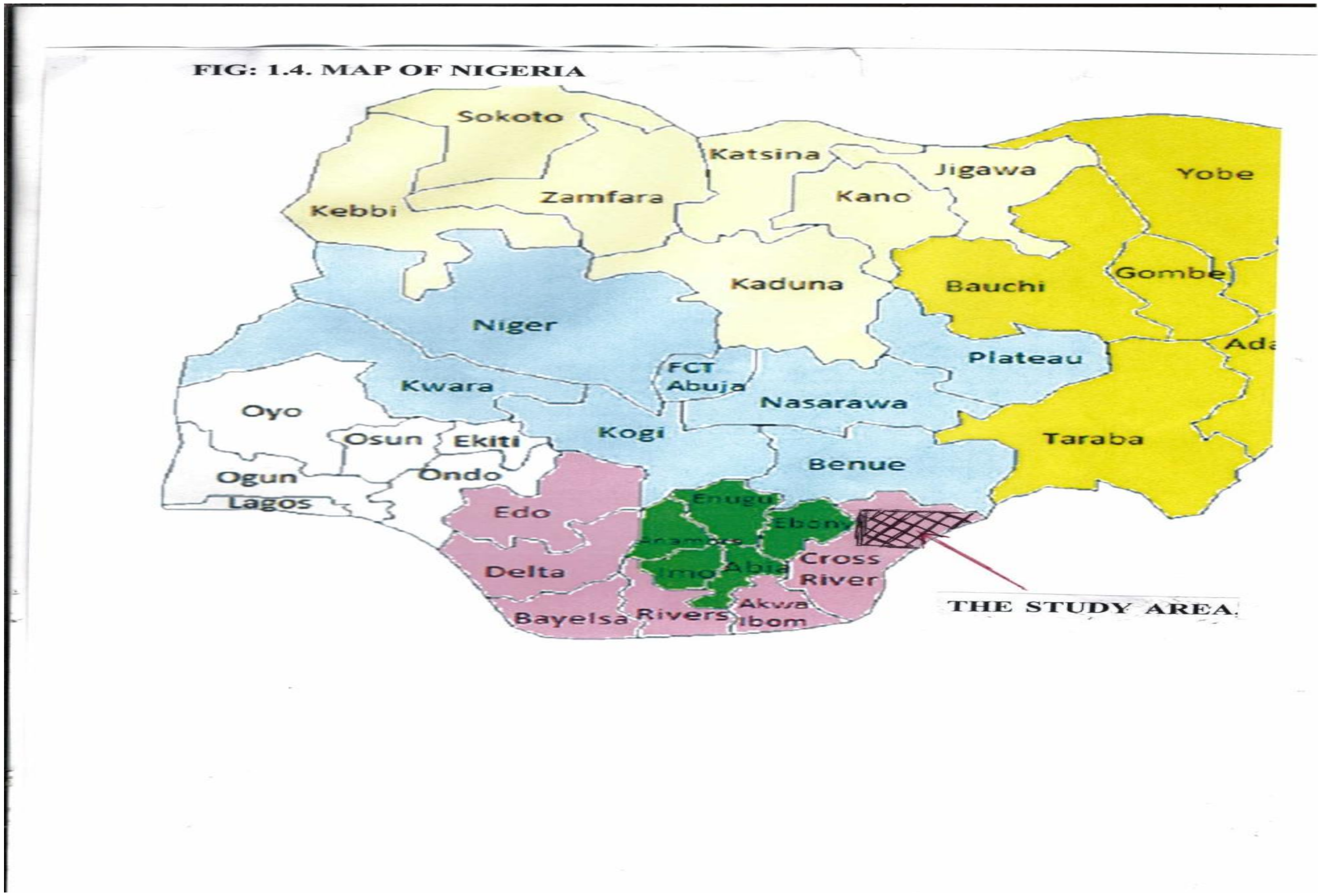

Fig. 4. Map of Nigeria

6. ENVIRONMENT AND DATA ANALYSIS

The study area (Obudu and Obanliku Local Government Areas of Cross River State, Nigeria) is situated within the Niger Delta region in the tropical rain forest belt. It lies between latitude 5°32[1] and 4°27[1] North and longitude 7°50[1] and 9°28[1] East, with temperature ranging between 15°c – 30°c and annual rainfall between 1300 – 3000mm [5].

Fifteen (15) locations of water for drinking and other domestic uses were carefully studied including their surface to water depth (surface depth) values recorded. Five of the fifteen locations are exposed Water Saturated Depression (WSD1, WSD2, WSD3, WSD4, and WSD5) with water coming out from the ground, located in valleys with surface run-off and leachate, which might contain all forms of waste, including human waste within the anticline, driven into the water. Communities with children are depending on this water for drinking and other purposes; while seven (7) of the fifteen (15) locations (Well 1, well 2, Well 3, Well 4, Well 5, Well 6, and Well 7), are hand dug wells at shallow depth. The remaining three of the fifteen (15) locations are bore holes (BH 1, BH 2, and BH 3) with significant surface depth value.

Physiochemical composition analysis for all the fifteen locations water have been carried out comparing the value with the World Health Organization (WHO) standard.

Table 5. Alowable minimum distance to some infrastructures in hand dug well

Existing structures	Minimum distance
Buildings	3
Soakaways	30
Dump sites and burial grounds	500

Source: Ministry of Water Resources, Cross River State, Nigeria

Table 6. Approximate surface depth values for the hand dug wells

Wells	Depth values (in meters)
Well 1	10m
Well 2	8m
Well 3	11m
Well 4	8m
Well 5	10m
Well 6	8m
Well 7	11m

Source: Hilili J. et al.,Field work, [14]

Table 7. Approximate surface depth values for bore holes (in metres)

Bore Holes	Depth Values
BH 1	107m
BH 2	80m
BH 3	105m

Source: Hilili J. et al., Field work, [14]

Table 8. Physiochemical composition standard

S/N	PARAMETER	WHO STANDARD	NIS STANDARD
1	PH	6 to 8.5	6 to 9.2
2	Electrical conductivity	1 ms/cm	1 ms/cm
3	Temperature (^{o}c)	Not mentioned	Not mentioned
4	Colour	15Tcu	15 TCU
5	Turbidity	5 NTU	5 NTU
6	Nitrate	50 mg/l	50 mg/l
7	Iron	1.0 mg/l	0.3 mg/l
8	Phosphate	0.3 mg/l	0.3 mg/l
9	Calcium	75 mg/l	75 mg/l
10	Flouride	1.5 mg/l	1.5 mg/l

Source: WHO in Lenntech [15] and Oloyede-Kosoko et al [16]

Table 9. Physiochemical composition for seven hand dug wells: well 1, well 2, well 3, well 4, well5, well 6, well 7, and who standard

Hand dug Wells/ Parameters	**Well 1**	**Well 2**	**Well3**	**Well 4**	**Well 5**	**Well 6**	**Well 7**	**Well 8**
PH	7	8	6.5	7	8.2	6.5	7.5	6 to 8.5
Electrical conductivity	1.2ms/cm	1.3ms/cm	1.1ms/cm	1.5ms/cm	1.3ms/cm	1.5ms/cm	1.3ms/cm	1 ms/cm
Color	16 TCU	17TCU	15TCU	14.5TCU	16TCU	17TCU	16TCU	15TCU
Turbidity	5NTU	5.5 NTU	5.6NTU	5.3NTU	5NTU	5.7NTU	5.8NTU	5NTU
Nitrate	60mg/l	52mg/l	80mg/l	58mg/l	69mg/l	60mg/l	58mg/l	50mg/l
Iron	1.2mg/l	1.5mg/l	1.1mg	1.4mg/l	1.3mg/l	1.2mg/l	1.3mg/l	1.0mgl
Phosphate	0.8mg/l	0.4mg/l	1.7mgl	0.8mg/l	1.2mg/l	1.2mg/l	0.8mg/l	0.3mg/l
Calcium	63mg/l	70mg/l	71mg/l	73mg/l	72mg/l	50mg/l	54mg/l	75mg/l
Fluoride	1.3mg/l	1.2mg/l	1.0mg/l	1.0mgl	0.9mg/l	0.8mg/l	1.0mg/l	1.5mg/l
Coliform count	0 CFU/ 100ml	Detected CFU/ 100ml	0 CFU/ 100ml	Detected CFU/100nl	0 CFU/ 100ml	Detected CFU/100ml	0 CFU/ 100ml	0 CFU/ 100ml

Source: Hilili J. et al.,Field work, [14]

Table 10. Physiochemical composition, forthree bore holes (BH1, BH1, BH2, BH3) WATER samples and who standard

Bore holes/parameters	**Bh1**	**Bh2**	**Bh3**	**Who staandard**
PH	7.2	7.5	8	6 to 8.5
Electrical conductivity Conductivity	1.2ms/cm	1.3ms/cm	1.4ms/cm	1ms/cm
Color	15.2 TCM	14.5 TCU	14.9 TCU	15TCU
Turbidity	5NTU	5.1NTU	5.2NTU	5NTU
Nitrate	40mg/l	35mg/l	30mg/l	l50mg/l
Iron	0.5mg/l	0.9mg/l	0.9mg/l	1.0mgl
Phosphate	0.1mgl	0.1mg/l	0.1mg/l	0.3mg/l
Calcium	65mg/l	60mg/l	63mg/l	75mg/l
Fluoride	1.1mg/l	1.2mg/l	1.4mg/l	1.5mg/l
Coliform Count	OCFU/100ml	OCFU/100ml	OCFU/100ml	OCFU/100

Source: Hilili J. et al.,Field work, [14] The topography of the area is highly undulating, with hills, valleys and swarms. Fig. 5: shows map of the study area, with the water locations, dumpsite, market and farm lands. The study reveals that most dump site and soakaways distances from drinking water source locations, violate the specification given by the Ministry of Water Resources, which is the likely source of contamination to surface and borehole water as seen in the significantly detected coliform count in WSD3, WSD5, and in Well 2, Well 4, Well 6 of the hand dug Wells., we can link the health challenges related to water in these communities to their drinking water sources. The approximate surface depth values for seven (7) hand dug wells (Well 1, Well 2, Well 3, Well 4, Well 5, Well 6 and Well 7) were recorded. The highest "surface to water depth", was 11m, for Well 1 and Well 7, while the least depth were Well 2, Well 4, and Well 6, with about 3.5 meters" surface to water depth" each, and their water source is likely from unconfined saturated water zones; . The depth of pit toilets within these communities on average is about 4-5 meters, and their locations not far from their water drinking sources. This shows that, there is likely a possibility for a well to be contaminated at the subsurface with these unengineered soakaways. The presence of Coliform count is an indication of the presence of likely diseases causing organism as a result of biogenic interference. The increase in the concentration of nitrate and phosphate levels, significantly above the WHO standard in WSD 1, WSD 2, WSD 3, WSD4, WSD5, and Well 1, Well 2, Well 3, Well 4, well5, well6 and Well 7, is likely as a result of leaching and erosional activities of inorganic fertilizer from farm lands and effects from the waste dumps. Residents in these areas are mostly farmers, who replenish the soil nutrients with mostly inorganic fertilizers. The analysis also show that, the water from the three boreholes, BH 1, BH2, and BH 3, are the best for drinking and other domestic uses, without treatment, no coliform count unit/100ml of water were detected, and the nitrate and phosphate levels were also tolerable when compared to the WHO standards, probably due to their depth distances away from contaminants. It is important to note that the bore holes could locate aquifers between a depth of 80m – 107m; the hand dug wells had water at a depth of 11m within the same region of less than 30km distance apart. The differences in depth between the bore holes and the hand dug wells is significantly higher for the hand dug wells to be sure of safe water. Majority of the people in the region depend mostly on hand dug wells, and exposed water saturated depressions for drinking and other domestic purposes. Due to poverty and lack of knowledge, most people in these regions cannot afford the cost of constructing bore hole, thus, making it difficult for the people to access good and healthy water from confined aquifers in the subsurface.

7. RELATIONSHIP BETWEEN GEOLOGY, HYDROLOGY AND GROUND WATER CONTAMINATION

Geology deals with the origin and structures of hard rocks, soft rocks, and their geodynamic processes. Porous rocks such as sand stones, limestone and fractured rocks provide good characteristics for the different types of aquifers and other water retaining structures. For an aquifer to be confined, "the geometric four way closures" must be guided by an impervious rock such as clay, shale etc. Geodynamic processes such as folding, faulting, uplift, subsidence and intrusions have resulted to subsurface deformation, distribution, reorganization of aquifers and their contaminations. The vertical and lateral distribution of ground water and the conditions under which they exist (hydrology) depends on the geology of that area. The quality of ground water depends on the aquifer characteristics such as, rock type, porosity, structural defects, and the extent of external influx of contaminant. Most coastal aquifers have witnessed sea water intrusion, as a result of transgression of the marine environment, either recent or ancient depositional system, this account for high salinity and PH values in some ground water [17]. The extent at which ground water may be contaminated depends on the depth of the aquifer, distance from surface and subsurface contamination (soakaways, dump sites), permeability of the aquifer, tectonic history of the region, mining activities, and the surrounding country rock type.

Table 11. Physiochemical composition for 5 locations of water saturated depression

WELLS/PARAMETERS	WS1	WSD2	WSD3	WSD4	WSD5
PH	6.2	6	5.2	8.0	5.5
Electrical conductivity	1.2ms/cm	1.3ms/cm	1.4ms/cm	1.2ms/cm	1.1ms/cm
Color	15TCU	15TCU	15.7TCU	16TCU	16.5TCU
Turbidity	6NTU	5.5NTU	5.6NTU	5.3NTU	5.8NTU
Nitrate	60mg/l	72mg/l	79mg/l	77mg/l	80mg/l
Iron	1.2mg/l	1.5mg/l	1.8mg/l	1.3mg/l	1.9mg/l
Phosphate	0.5mg/l	0.7mg/l	0.8mg/l	0.6mg/l	0.8mg/l
Calcium	76mg/l	78mg/l	80mg/l	79mg/l	82mg/l
Fluoride	1.7mg/l	1.7mg/l	1.9mg/l	1.7mg/l	2.0mg/l
Coliform count	0 CFU/ 100ml	0 CFU/ 100ml	Detected CFU /100ml	0 CFU/ 100ml	Detected CFU/100ml

Source: Hilili J. et al.,Field work, [14]

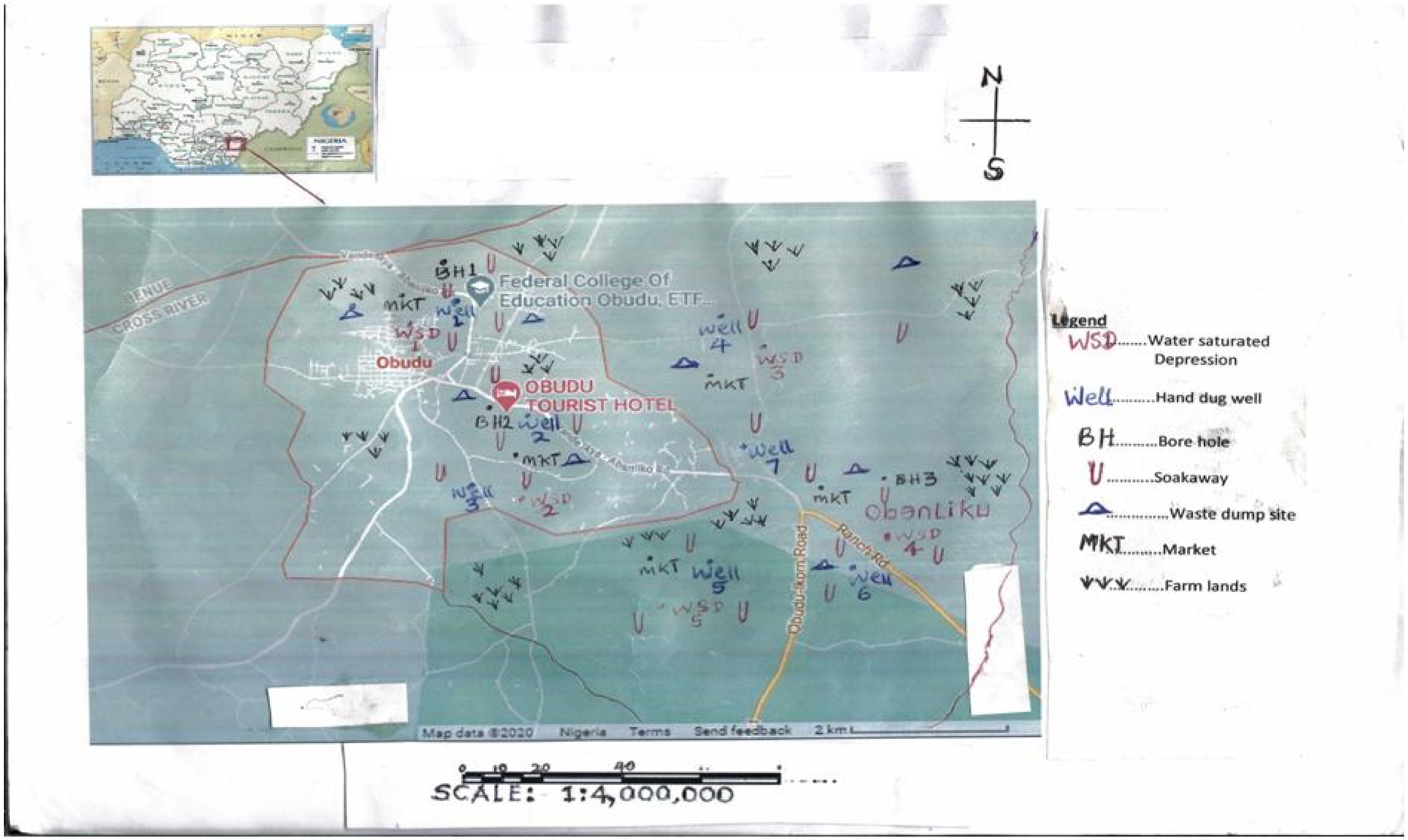

Fig. 5. Map of the study area, showing location of the water source, Soakaways, Dumpsite, market and farm lands

8. REMEDIES TO GROUND WATER CONTAMINATION

A. Constructional Remedies:

i. Pit toilet location should be investigated and constructed based on safe recommendations of hydrologists and sanitary inspectors.
ii. Engineered dumped sites should be used rather than indiscriminate unsafe dumps.
iii. Effective waste collection methods should be implemented.
iv. Best practices in hydrocarbon exploration and exploitation geophysical methods, such as the use of seismic method.
v. Transportation routes should be strengthened and guided to avoid oil spills in land and water.
vi. Geological reports on subsurface geometries and characteristics of beds should be made available, to serve as a guide to bore hole drillers.

B. Analytical Remedies:

i. Water used for drinking and other purposes should be properly analyzed in line with WHO standard before being used by the people
ii. Test for heavy metals content and other forms of contaminants on ground water should be conducted [17].
iii. Safe and confined aquifer depth for ground water should be investigated and analyzed in human inhabited areas.

C. The Role of Government:

i. Where it is difficult to treat and supply water to the people, government should sponsor investigation of subsurface structures and geometries in human inhabited areas to fore store health challenges
ii. Education on water treatment and quality should be made available to the people.
iii. Countries should make available significant percentage of funds in their yearly budgetary allocations
iv. Vaccines on water borne diseases should be made available to the people as a preventive measure.

9. CHALLENGES

1. Constrain in water analyzing instruments
2. Financial challenges.

10. CONCLUSION

Ground water can be contaminate through human activities such as ; agriculture, mining, construction of soakaways, exploration and exploitation of hydrocarbon, improper management of waste, and natural activities such as, sea water intrusion, daiperic salt intrusions, earth quake, landslides, and other geodynamic processes. To access good drinking water in line with WHO standard, there is need for effective management of human, industrial, agricultural waste at the surface and sub-surface including geodynamic activities in the area. Farmers should be educated on internationally acceptable best practices in farming, such as preferring organic easily biodegradable fertilizers to the inorganic fertilizers. Bore holes are most likely to produce healthy drinking water than hand dug wells and water in saturated water zones on the earth surface, this is due to the proximity of the later to contaminants. However, in constructing bore holes for drinking and other domestic uses, the necessary safety hydro-engineering roles must be obeyed, such as appropriate wells blinding with depth, good quality materials, analysis of cores, test of the suitability of the water for drinking and other domestic uses including good water storage facilities. Where necessary, hand dug wells should go beyond 5 meters in line with the recommendations given by the Ministry of water Resources on buildings, soakaways and dump site distances. The government of every nation should be interested in the provision of good drinking water to its citizens to prevent the occurrence and outbreak of epidemics and pandemics associated with water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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