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Groundwater occurrence and flow in varying geological formations

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Abstract. Groundwater includes water that is formed within the unsaturated zone (soil), above the water table (capillary fringe) and below the water table. Its occurrence is everywhere, and it is restricted to a maximum of 750 m depth in the near surface. Groundwater availability within the subsurface formation has become a primary concern to the geoscientists because the dependency of surface water has been limited and declined due to it inadequate yield during the period of a year and also the surface contaminant which affect its quality and potential. The investigation of groundwater in the near surface has been a major principal discovery which has served both the domestic, commercial, agricultural and industrial purposes and to understand the continuity of groundwater availability within the subsurface, a study on occurrence and flow of groundwater is highly significant. Understanding the flow pattern is a major constituent in productive groundwater exploitation and exploration. Therefore, this review has been design to place emphasis on the occurrence and flow of groundwater in the near surface, which is one of the agenda of the Sustainable Development Goals.

Keywords: Groundwater, Sustainability, Aquifer, Near surface features, Geological formations

1. Introduction

Water is basically referred to as the medicine of life which is essential for sustainable development within the environment [1, 2]. Being a universal solvent of the earth crust, its major sources include groundwater (such as boreholes and wells) and surface water (such as rivers, springs and fresh water bodies) [3, 4]. In addition, humans had placed more attention on surface water as part of the hydrological cycle [5] but however, authors such as Salako and Adepelumi [2], Wali et al. [6] and Bayowa et al. [7] have shown that the safest and reliable means for water availability is the use of groundwater. Groundwater is the maximum abundance supply of water to be had for human consumption due to the fact that it is far extra advantageous as a supply of potable water. It is highly important since its availability is a major factor that promotes a healthy and favourable environment for humans. Groundwater has featured prominently in environmental sustainable development of water resource management over the years; because it is not generally susceptible to pollution as surface water does [7 - 11].

The occurrence of groundwater is based on the geology of the subsurface formation, which is categorized into three ways; fractured/weathered aquifers in hard rock terrain, sandstone/grit aquifers in the sedimentary rock terrain and sandstone/conglomerate/fractured rocks in geologic hard areas [12]. In Nigeria, the two major hydrogeological units are basement rocks and sedimentary basins [7]. These hydrogeological units possessed their distinct characteristics in terms of groundwater potential [13]. Examples of hydrogeological exploration from crystalline basement terrain and sedimentary terrain had been presented by the following references [7, 14 – 19]. More also, the sedimentary terrains are majorly subaquatic or subaerial region on the earth surface where sediments have amassed at a larger rate and to a greater thickness than they have in other adjacent nearby areas. Meanwhile, the basement complex depicts rocks underlying the sedimentary rocks which are characterized with weathered and jointed or fractured or sheared or faulted columns [6, 20]. Groundwater could be explored within the sedimentary formation where its quest is less difficult to achieve and also at the basement complex where its quest is difficult to manage [9].

Groundwater is present at everywhere and varies from 0 to 750 m depths at the near surface. The major sources of water include: connate, meteoric, juvenile and condensational water. Connates are liquid molecules being trapped within the pores of sedimentary rocks at the deposition time. Connates are saline and are present in many mineral components as ions. These liquids are discharged in the subsurface as rocks undergo lithification. Meanwhile, trapped liquids that could not be discharged are built up as overpressured zones in the rocks. Meteorics are major part of underground water. They are liquids being derived from precipitation. It is originated from the atmosphere by evaporation and falls as rain. It becomes groundwater within the saturation zone (aquifers) through infiltration processes. Juveniles are originated from the Earth's interior, which are associated with the magmatic processes beneath the Crust. Magmatic water arises from vapour-formed magma intrusions at great depth, which condenses into hot water. The hot water moves upwardly from high temperature and pressure zone to a very low temperature and pressure zone. The water being formed through these magmatic activities is known as virgin water. Condensational water is the main water source that replenishes the groundwater system in desert and semi-desert zones. The continental air in the summer becomes warmer than the trapped air in the near surface, which leads to pressure variations between the media. As a result of pressure gradient, the atmospheric water vapour being trapped in rock pores are converted into water through condensation (under low temperature). This process could lead to water accumulation in rocks within arid and desert environments.

For an appreciable amount of groundwater to be stored in aquifers for exploitation, the finite combination of the groundwater flow pattern, aquifer system and the mode of recharge is essentially needed which jointly formed an integrated dynamics of the groundwater system [21]. Thus, the purpose of this proceeding is to briefly review the occurrence and flow of groundwater system in both basement complex and sedimentary terrain for balanced utilization of groundwater resource and sustainable water management in our environment for actualization of the sixth goal of the Sustainable Development Goal (SDG), which mandates availability and sustainable water management for all in the next decade [22].

2. Aquifer Classification

Any geological structure associated with a homogenously or tightly organized texture will exhibit a high rate of porosity but less permeability, while formations with higher permeability and higher porosity possess sufficient yield of significant amounts of groundwater to wells and springs [2]. Aquifers are typically acknowledged to function as reservoir and could dry up quicker by human activities than they may have been recharged. Aquifer could have high porosity and low permeability while others can have high porosity and high permeability. In addition, aquifers with excessive porosity and low permeability are called poor aquifers at the same time those with excessive porosity and excessive permeability are called good aquifers [2]. Geological structures with the above characteristic are referred to as aquifers.

Aquifer is defined as a rock formation that contains enough groundwater which could benefit mankind for domestic, industrial and agricultural usage. According to the geologic terms, aquifer may well be remarked as a body of saturated rock or geological formation through which water could permeate into wells and stream as shown in Fig. 1. An aquifer is a distinctive geological formation, despite the fact that some are extra established than the other [23]. The boundaries of an aquifer are typically gradational into some other aquifer in order that an aquifer may be a part of some other aquifer system.

An aquifer is generally classified into two main divisions which include a confined aquifer and an unconfined aquifer [24]. A confined aquifer is a formation with the presence of an impermeable rock layer that prevents water from seeping into the aquifer apart from its area of recharge [2, 24]. A confined aquifer could also be an aquifer that is found to be overlain by confined rock layer often made up of clayey materials which often form some protection from surface contaminant. Groundwater can be protected in a confined aquifer and water can seep into the confined aquifers from a far distance, in which the impermeable layer does no longer exist.

Consequently, an unconfined aquifer is the one where water could seep into a formation from the overlying layer. An unconfined aquifer in contrast could be observed close to the land surface and do not have any layer of clay or different impermeable geological substances above the water table, even though it could be observed above impermeable clay rock layers [2, 24]. The groundwater in an unconfined aquifer is greatly prone to contaminations from the surface pollutants. Fig. 2 shows the illustration of a confirmed aquifer and an unconfined aquifer.

3. Groundwater in the Basement Complex

Aquifer units are basically characterized by relatively low yield in most parts of the basement complex [20]. Examples of low aquifer yields have been identified in the studies of Wali et al. [6], and Obiora et al. [26]. It is important to explore groundwater potentials in basement complex due to the nature of aquifers in this kind of terrain. In basement complex, aquifers are isolated and compartmentalized. In the undeformed state, these aquifers contain little or no porosity and permeability. Due to this nature, occurrence of groundwater is dependent on the development of secondary porosity and permeability by weathered rocks and fractured bedrocks [10, 14, 27]. Weathered basement aquifer is usually of low permeability even if it is of high porosity, this is as a result of the high clayey contents within the intergranular pore spaces within these aquifers. In view of this, aquifers in basement complex could possess high storage capacity, without a secondary permeability, the transmissivity will be low [20]. Fractured bedrocks within the clayey components in the crystalline basement terrain are examples of confined aquifers [28].

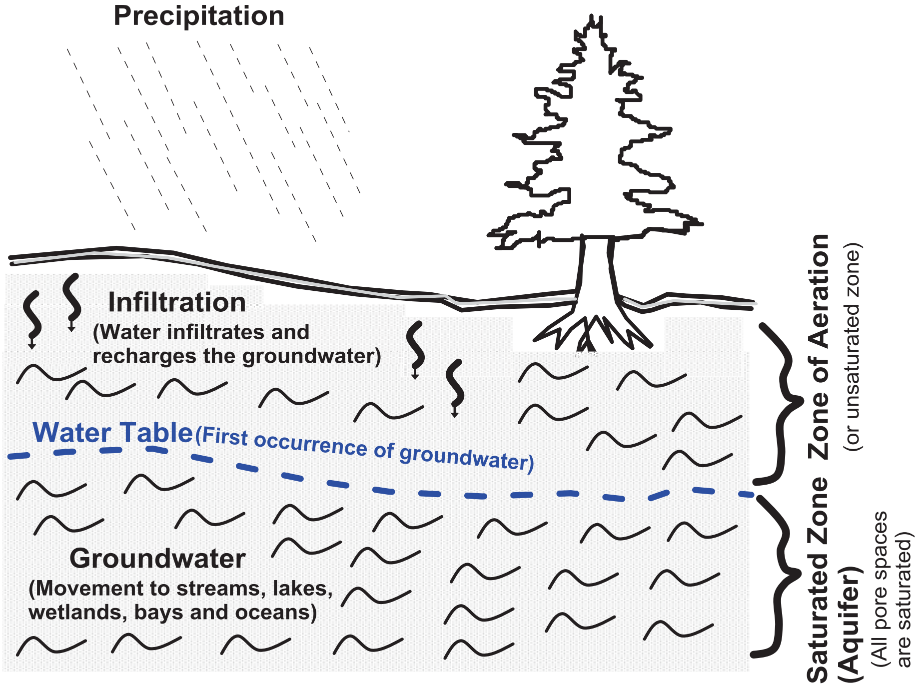

Fig. 1: The aquifer formation

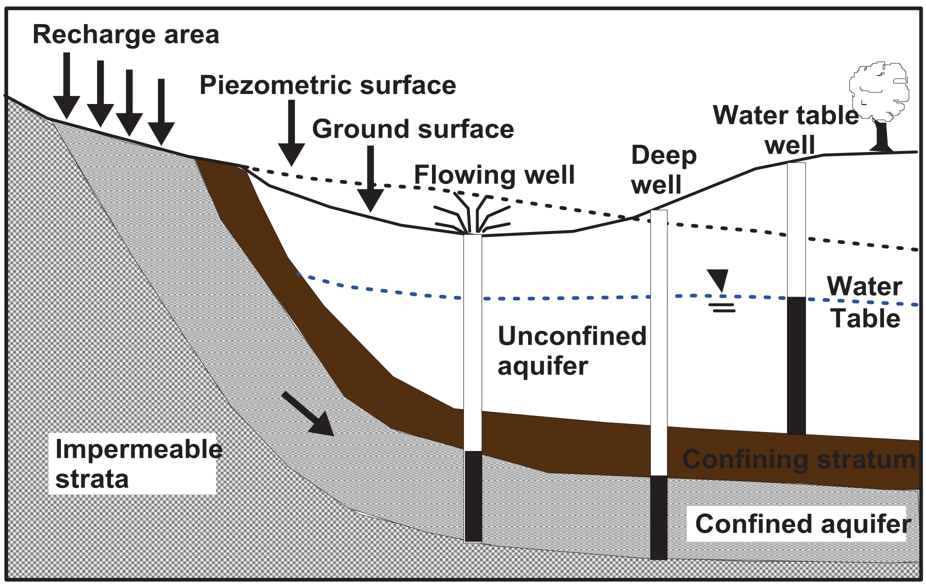

Fig. 2: The schematic cross-section of aquifer classification

Furthermore, groundwater storage in the basement terrain is dependent on the depth and thickness of the weathered rock and the strength of the underlying fractured parent rocks. Highly fractured or deep seated weathered zones form a good aquifer in basement complex. The thickness of the weathered overburden and the fractured zones determines the strength of groundwater dynamics. In order to identify appropriate locations for these aquifers in the basement complex, it is imperative to integrate the geological and hydrogeological knowledge of the area of interest with the geophysical survey (preferably electrical resistivity method using Schlumberger array and/or electromagnetic method) [4, 10, 23]. Groundwater that is free from pollution (through anthropogenic activities) can be exploited within faulted bedrocks at great depth while the aquifer within weathered layer is usually occur at shallow depth that is prone to pollution. The quality of water resource that is free from pollution in the deep seated fractured zones can easily be reached by drilling of boreholes which are usually expensive and not readily accessible by the populace. This allows the masses to rely solely on hand-dug wells which are supplied from the shallow water table within the weathered overburden. The hydrogeological domains of basement rocks in Africa and Nigeria are shown in Fig. 3.

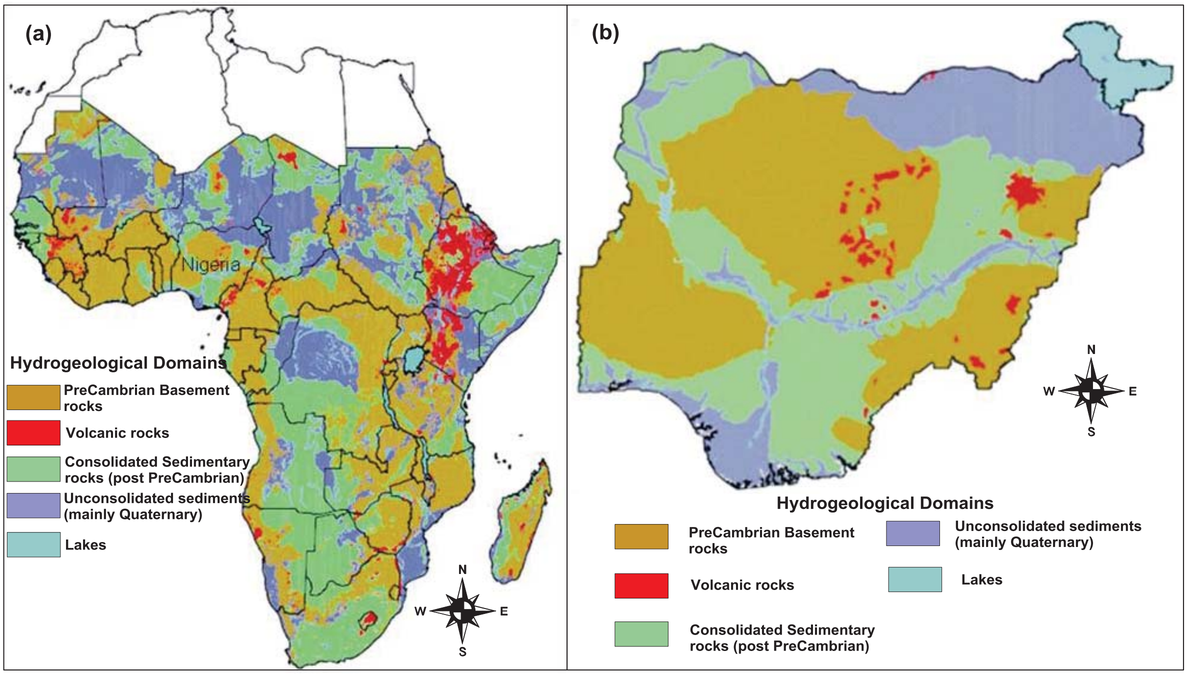

Fig. 3: Hydrogeological domains in (a) Africa (b) Nigeria (Adapted from [14] and [30]).

4. Groundwater in the Sedimentary Terrains

The conditions of groundwater occurrence and flow in the sedimentary basins are very different from those of the inter-mountain sediments or volcanic rocks [29]. The difference is determined mainly by the tectonics of their structures, the degree of fossil rocks, and the deviance of the sedimentary rocks. Sediments deposited from these structures maintain primary sediment porosity which controls their storage capacity and permeability. The fractured porous rock formation is mainly composed of sedimentary carbonate rock and clay such as limestone, dolomite and a deep part in the fossil structure of sedimentary rocks such as sandstone and siltstone [29].

The flow of groundwater in sedimentary terrain is neutral as a result of the combined influence of increase in sediments, hydrocarbon generating from organic matter, aqua-thermal effects and at more depths, the dehydration of clay minerals. Sedimentary terrain possesses an aquifer of unconsolidated sediments that has satisfactory permeability to allow the ease of flow of water through it [29]. An unconsolidated resource like gravel, sand, or even silt makes relatively dependable aquifers in sedimentary terrain [13]. Due to the relatively weak sedimentation and tectonic divisions, the hydrogeological formations of the sediments generally have a heterogeneous layered structure within the aquiferous zones. Sand, sandstone, fractured limestone or karst, and dolomite are generally the main aquifer rocks [29]. The groundwater flow involves the structural plane of the crystalline bedrock of the basin and the lower part of the sedimentary rocks formed in aquifers. The hydrogeological domains of sedimentary basins in Africa and Nigeria are shown in Fig. 3.

5. Recharge Pattern of Groundwater

Recharging is not only based on small or large storage capacity, it is important because an understanding of the processes and quantities involved increases the knowledge of its occurrence and potentials [31]. The main source of groundwater recharge could be the down pour precipitation of rainfall, which eventually infiltrates water discharge from streams, lakes or reservoirs and infiltration from irrigation canals (see Fig. 4). Sedimentary and basement complex aquifers depend on natural precipitation or artificial sources through irrigation of land for their recharge and sustainability [32]. Groundwater aquifers are distinguished by their appearances, their characteristics are largely as a result of the interplay of weathering processes being related to groundwater recharge and flow [31]. Aquifer recharge includes vertical recharge due to precipitation and onshore flooding through permeable topsoil, river runoff into the aquifer and leakage through high-density mantle and/or low permeability [24].

The size of the rock, the voids between the rock and the soil particles could be used to determine the rate at which water enters, passes and leaves the aquifer. A basic overview of recharge in a typical sedimentary topography is achieved by the flow of atmospheric precipitation and groundwater from the vicinity of relatively high elevations and also by seepage from aquifers and water in the periphery of the basin.

6. Conclusion

The role of groundwater management (its occurrence and dynamics) for actualization of the SDG agenda in human environment cannot be overemphasized. The sedimentary terrains can be of little or no complexities when investigating (Fig. 5a) but however, the basement complex need to be well understood because of the complexities attached to it (Fig. 5b). This suggest that in-depth study of the dynamics of the system is needed to better understand groundwater potential in terms of the yield, storage, and occurrence of groundwater in various geological terrains. It has also been found that the application of computer modeling and mathematical tools can be used to analyze the dynamics of groundwater systems in the near surface.

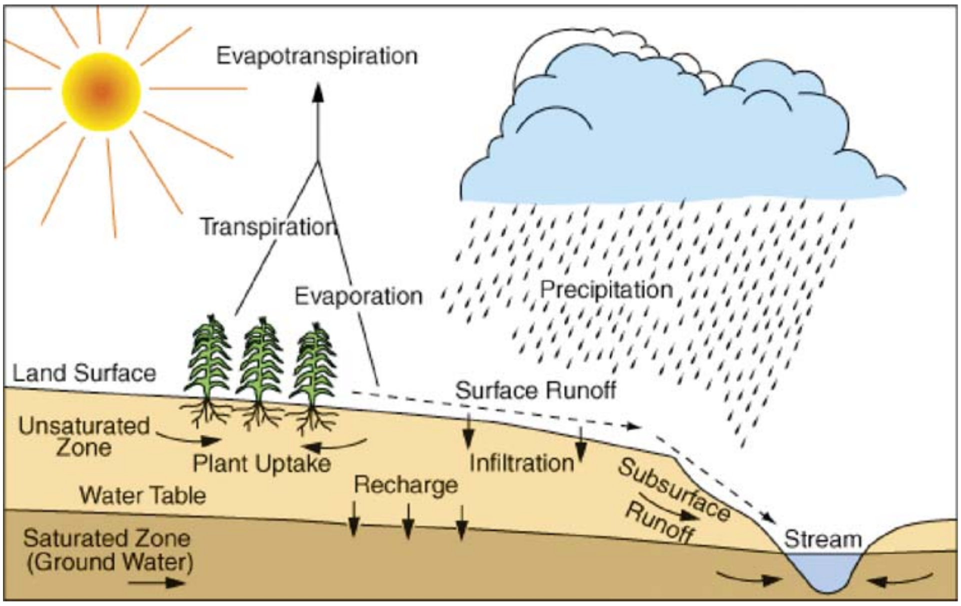

Fig. 4: The recharge pattern of groundwater

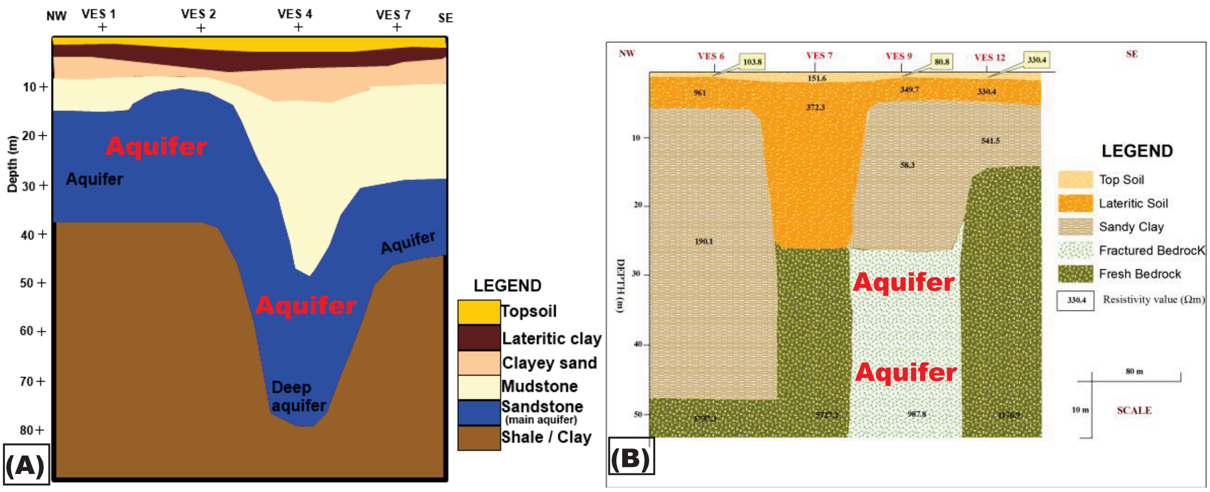

Fig. 5: Derived geoelectric sections within: (A) a sedimentary terrain [18], and (B) a basement complex rocks [33]

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