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Cross-Sectional Spatial Simulation of Groundwater Resource Aquifers in Arid and Semi-Arid Regions of Nigeria

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ABSTRACT

Recent climatic volatility within the Arid and Semi-Arid regions of Nigeria has greatly affected the ever buffering groundwater aquifers of this region. Though, the region explicitly depends on it groundwater resources for it various domestic, agricultural as well as industrial activities. However, these groundwater resources still remained the most important source of water due to it' pureness, reliability and can be developed at relatively cheaper rate besides facing nonstop cruelty, over exploitation and treats from both natural as well as anthropogenic activities. Therefore, in order to succinctly understand the region groundwater aquifers, the present study construct a cross-sectional simulation of the region' groundwater and their respective aquifers using QGIS software for system. The study discovered that recent water resource have experienced an undeniable progress within the North-East region. Moreover, the groundwater aquifers of the are also found to be naturally endowed with budding economic worth that can significantly fast tracked the region's various developmental needs (worth's millions of dollars) when effectively utilized.

Keywords: Geographic Information System, Natural Resource Management, Integrated Water Resource Management, Regional Development, Spatial Relationships, North-Eastern Nigeria

1. INTRODUCTION

Among the key uncertainties in natural resource management in Africa is the management of groundwater resource especially in the regions within the arid and semi-arid region. With recent climatic volatility, most of these regions significantly depended on their respective groundwater resources for domestic, agricultural and industrial activities. Groundwater resource resources remained the most important source of water due to it' pureness, reliability and can be developed at relatively cheaper rate. Hence, groundwater tends to be of good quality, as it is protected from surface contamination [1]. With recent ever increasing temperature around the World, a study by Fasanmi et al. [2] proved that for Africa as a whole, warming in the 20th Century occurred at a rate of about 0.5^{o}C across the century, and that the rate of warming increased in its last three decades. In future, based on predictions under the medium-high greenhouse gas emissions scenario, annual mean air temperature between 2080 and 2099 is expected to be 3 to 4^{o}C higher than it was between 1980 and 1999 [3]. On

the other hand, the annual rainfall is likely to fall in the Northern Sahara and in Southern Africa, where there is also the likelihood of increasing around the Ethiopian Highlands [3]. Hence, wider predictions are difficult to make as changes in precipitation are much less certain than those for temperature, particularly for the Sahel and the West African coast.

The four African regions used in the regional analysis of IPCC (2007) are large and climatically heterogeneous, and while higher resolution analysis is clearly needed, yet the current regional models fail to succinctly prove that downscale precipitation over Africa is possible [4]. Recent downscaling of models to the level of large river basins with current circulation models may produce more hydrological 'noise', rather than clearer insight. However, the rainfall variability is likely to become increasingly unpredictable in terms of both intensity and duration, with increases in the frequency of extreme events; i.e. droughts and floods [4]. Mean annual rainfall is already highly variable across Africa, ranging from almost zero over parts of the Sahara to around 10,000 mm in the Gulf of Guinea [4]. Inter-annual and seasonal variability is likely to increase. Therefore the needs for spatial analysis become paramount in order to examine how Earth's processes interact over space or area. This form of analysis allows individuals to solve complex location-oriented problems and better understand where and what is occurring in your world. It goes beyond mere mapping to let you study the characteristics of places and the relationships between them. Hence, a spatial analysis strives to lend new perspectives to your decision-making.

Nigeria is naturally endowed with about 224 trillion l/year of surface water and also about 50 million trillion l/year of groundwater [5]. With recent estimated population of almost 200 million people according National Bureau of Statistics (NBC), for instance, as of early 2000, the domestic consumption need of water resources was about 6.0 billion l/year besides having a population of about 120 million people only [6]. Lack of adequate and appropriate hydro-geological base maps, poor knowledge of the geology of Nigerian terrain especially within the arid and semi-arid regions coupled with lack of infrastructural facilities and absence of a working legislature beset the practice of hydrogeology has compounded various issues and thereby resulted numerous problems in groundwater exploration, exploitation, operation, control and management. The present study is a cross-sectional study that attempts to simulate the groundwater resources aquifers of arid and semi-arid region of the region. Based on the informative nature of the study, the study delineates the recent groundwater aquifers as well as their respective productivities so as to necessitate better understanding among other things.

2. MATERIALS AND METHOD

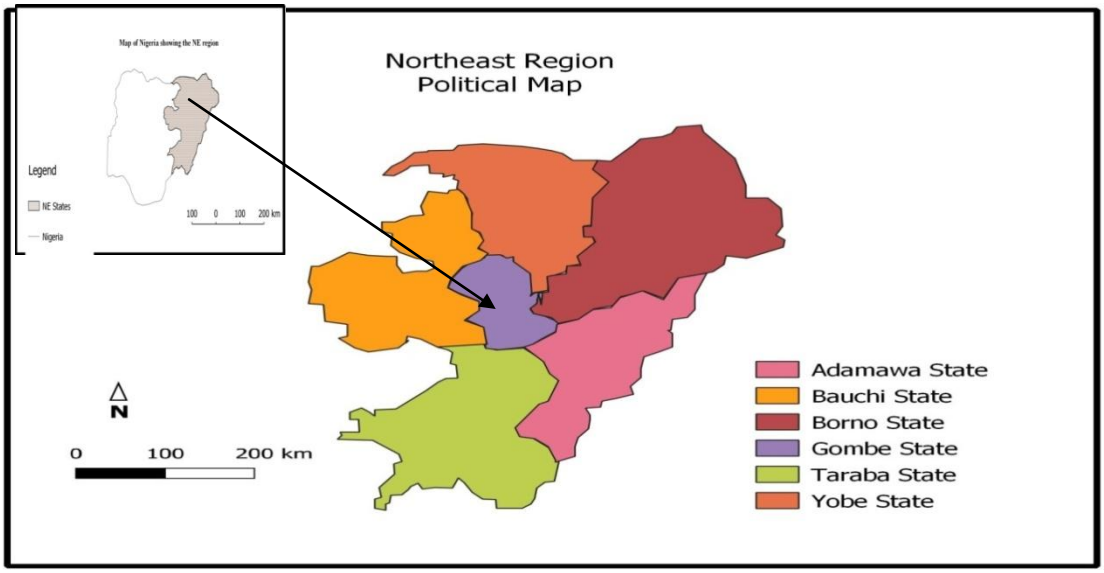
Based on the qualitative nature of data involved, the dataset used in the study was obtained from secondary sources by the author. These geographic information obtained were digitized using QGIS for proper analysis and interpretation of the region' groundwater aquifers as well as their respective productivity. These were also supplemented by key qualitative information reviewed from literature survey from various studies regarding the groundwater aquifers as well as the geology of the North-East region of Nigeria. The study also conducted a field trip to some selected areas within the study area in order to succinctly understand the ground reality issues

associated to some key concerns on groundwater aquifer and their respective productivity. However, the selection criterion adopted was probability sampling technique were specific locations are randomly selected within the North-East region of Nigeria for subject analysis.

2.1. Study Area

The present study was conducted in the Arid and Semi-Arid region of Nigeria, explicitly, the North-East Geopolitical Zone. The geopolitical division were first used by the then former Military Head of State, (late) General Sani Abacha in 1995. These partitioning were based on close geographical proximity and ethno-cultural affiliations. The six divisions are the North-East, Northwest, North-central, Southeast, Southwest and South-South respectively. With about 36 states and a Federal Capital Territory, however, the country is believed to be having more than 250 different ethnic groups with diverse cultures and dialects [7]. Therefore, the then Nigerian Government initiates these divisions to facilitate more efficient approach to various institutional and development initiatives, projects and programs. Though these divisions were criticized by some studies, yet, this study believed that this division has supported/aid minorities in numerous development aspects within the country.

Figure 1: Political Map of North-East Geopolitical Zone



Source: *Author, 2019*

3. RESULTS AND DISCUSSIONS

For thousands of years, humans have adapted to live within the limits of the water cycle. Groundwater has generally provided reliability in supplied in most arid and semi-arid arid regions of the World through periods of drought. Recently, various experts have agreed that global water crisis has developed largely due to poor resource management. This poor management of Earth water resource is scientifically and evidently clear that water withdrawals exceed natural rates of it' renewal or recharge [8]. As for the groundwater resources, it is

vital that finite amounts of any renewable resource can be recognised and quantified. In areas with low rainfall, geochemical techniques are well-suited to recharge estimation. Water quality issues also emerge which can threaten and further diminish the amounts of the renewable reserves. Salinity encroachment from excessive pumping (in addition to salinisation due to agriculture) poses considerable threats [8]. Other issues considered include naturally occurring high nitrate concentrations related to past vegetation cover and in some cases the high baseline concentrations of certain elements arising from natural geological environments. A sound scientific basis is yet required for improved water management for improved definition of the renewable resource and indications of non-renewable waters, water quality distribution and stratification and in providing early warning of change and the design of monitoring strategies. Above all an integration of available scientific evidence into policy making is badly needed [9].

In milieu of uncertainties and limited water datasets, sustainable exploitation of natural resource provides enormous rents and revenues that can fast track regional socioeconomic development and prosperity. The Nigerian economy has heavily dependent' on oil revenues (accounted for about 90 percent of total exports) and also constitutes about 75 percent of the country revenues [10]. This country Gross Domestic Product (GDP) was estimated at US$569,000 million in 2014, with about 20 percent of these contributions is from the conventional agricultural sector [10]. In Nigeria, agricultural sector is the largest employer and also solemnly provided occupation to about 31 percent of the economically active population in 2007 [10,11]. On the basis of Human Development Index (HDI) in 2014, like many West African States, Nigeria is ranked as 152nd among 188th countries having mere life expectancy of 53 years as well as the under-five mortality of about 113 per 1000 births [11]. Hence, within the geopolitical regions of Nigeria, the North-East region is among the regions with lowest HDI [9,11]. Therefore, in an attempt to minimized regional marginalization under uncertainties of climatic volatility and population explosion, fast tracking of North-East region development for efficient socioeconomic prosperity require absolute sustainable resource management.

With water as the king of all resources in the North-East region, the study attempted to evaluates the current water resource potential for developmental opportunities under the limited available data. The study understands that groundwater resource availability within the North-East region is greatly threatened by both natural as well as anthropogenic processes. Moreover, numerous other issues such as the existing water resource management, water laws, regulations and policies, water as a vehicle of socioeconomic activities, water a form of development tools, water accessibility and demands, quantity, quality, resilience and vulnerability. Moreover, the study also identified key likely anticipated groundwater resource hotspot areas within the North-East region are all spatially simulated and marked.

3.1 Groundwater Resource

The groundwater resource of the North-East region is the most important and perceived reliable source of freshwater in the region. The groundwater resource of this region is largely controlled by the hydrostratigraphy and the region' flow pattern of aquifers and aquitards occurrences [12]. There are significant patches of igneous

and metamorphic rocks in this region which made up the basement complex. The basement complex is a hard non water bearing (aquiclude) that mainly acquire secondary porosity due to weathering over reasonable geologic time with moderate to marginal water yield depth of 20 to 100 m [12]. Moreover, the extreme northern part of North-East region is characterized with higher temperature of as high as 44^{o}C during the summer [12].

Table 1: Groundwater resource hydrology (ha)

Hydrological area	**Groundwater resources** (m^3)	**2005**		**Est. 2020**	
		Demand (m^3)	Water use rate (%)	Demand (m^3)	Water use rate (%)
Nigeria	51,930	260	0.5	3,920	8
Northeast	5,580	60	1.0	620	11

***Source**: Computed from Ita and Petr, 1983; Genthon et al., 2015; Yusuf, 2015*

Based on the table 1 above, the study understands that the region's anticipated groundwater demand and use multiplied more ten percent. However, it was also expected that this region will also continue to suffer drastic decrease in annual rainfall [13]. Within the region, the study also found that the hydrological prospects of the good aquifers increases as one move to southward of the region, hence, the occurrences of this region groundwater resource with regards to water quantity and quality exhibits spatial variability that is determined by geology and climate. The groundwater recourses are greatly utilized for the regions' domestic, agricultural as well as the industrial activities [5]. Most of the reviewed studies on Nigeria's recent groundwater resource assessment and procedures have narrow-minded objectives in determining the most suitable practices and policies in light with international best practices. However, this study understands that management of groundwater resources of the North-East region lacks obvious coordinated approach and does not facilitates integrated regional management [14]. Besides being the most reliable source of fresh water throughout this region, it lacks considerable concerns both institutionally as well as at individualized level within the North-East region.

Groundwater resource is the most important source of freshwater that essentially contributes towards meeting this region existing water requirements and demands. The management of groundwater resource is paramount for the sustainability of the resource as well as reducing the level of poverty within the region. Due to the recent decreasing surface water resource and low rainfall within the North-East, the groundwater utilization and development have exceeded the required sustainable limit [15]. It is fact that key skills in maintenance of groundwater resource is striking a balance between water demands and supply in line with rational economic, political, environmental, technology, sustainability, quality and quantity framework [15,16,17]. Though, the recharge rate of the shallow groundwater in the uppers aquifers in most part of the North-East region is optimally significant and sustainable with the region rate of abstraction [15]. However, technical and scientific management expertise has been essential for any water resource use aimed at reducing wastage.

3.2 Recharge, Challenges and Threats

The existing water resource management practices in the region is found to be helplessly shortfall in competing with this region' increasing demands and priorities, therefore, establishing an up-to-date advance water management strategy is critical for ensuring the region' sustainable development. Water resource in the North-East region is facing numerous interconnected threats. However, water resource is indispensable tool for socioeconomic development and can consequentially results to socioeconomic prosperity, social security and political stability when sustainably utilized and properly managed. This study believed that the economic growth, prosperity and development of the North-East region have to some degrees significantly depended on the regions' groundwater resource and what happened to it'.

With only annual precipitation as the only source of recharge of this region' water resource. The total spatial precipitation of this region decreases northwards; from about 1250 to 1000 mm per year in the southern part of the North-East region to as low as 750 to 500 mm per year in the extreme Northern part of the Sahel Savannah region [18]. Moreover, temporal distribution of this region' annual precipitation duration also ranges between 4 to 3 months annually which the least at the extreme northern [12]. However, throughout the North-East region, for instance, unprotected wells are usually shallow and mostly diminishing aggressively during the drier season due to decreasing rainwater recharge [12].

The quantity and quality of this region water resource is significantly affected by budding natural as well as anthropogenic factors. The natural factors are the climatic variability and patterns, spatial distribution of the rainfall, diverse aquifers (confined and unconfined). The anthropogenic factors includes the various water uses and demands, agricultural activities, irrigation, use of synthetic fertilizers, wastages, wastes (domestic and industrials), etc. Within the region, various results have testified that seasonality significantly affects both water quantity (water quantity is higher during the rainy season) as well as water quality (during rainy season, there are a lot of runoffs to nearby water bodies and leaching of various compounds to groundwater) [7,9,12,1518].

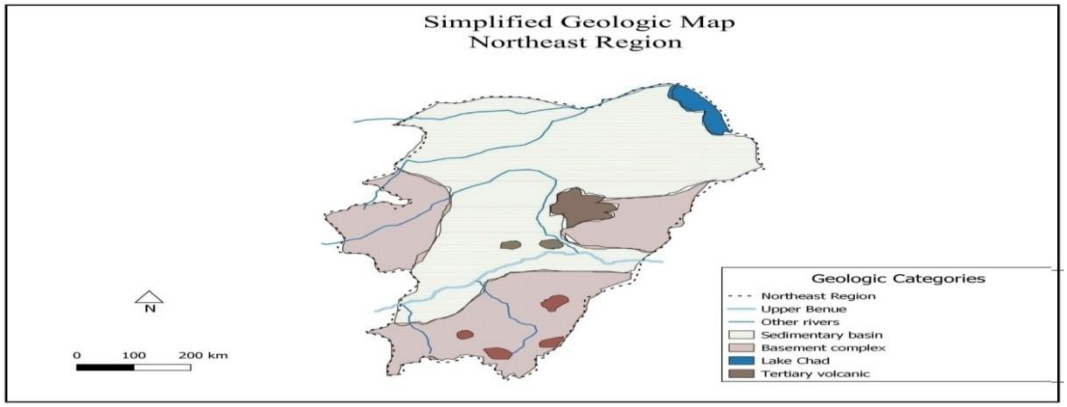
Within the North-East region, the present study understands that both the quantity as well as the quality of water resource is found to be decreasing and deteriorating respectively [19]. The quantity is found to be decreasing with recent ever-increasing demands, exploitations and uses greater than their rate of their replenishment [12]. For instance, within the North-East region, there are severe costs of dry season flow around the wetlands which were mainly characterized with blockage of channels and tributaries, excessive dry season flows as well as relentless reduction of flows. This region also suffer from artificial dry season flow, wastages of water, excessive overflow of channels and river beds remained wets all year round.

3.3 Geology and Aquifers Productivity

The geology across the North-East region are classified into three distinct categories: the sedimentary basin, basement complex and the tertiary volcanic. These geologic divisions are also referred as the Keri-keri, Pre-Cambrian and Chad formation [8,12,15]. The Keri-keri formation is considered to be unpredicted and largely

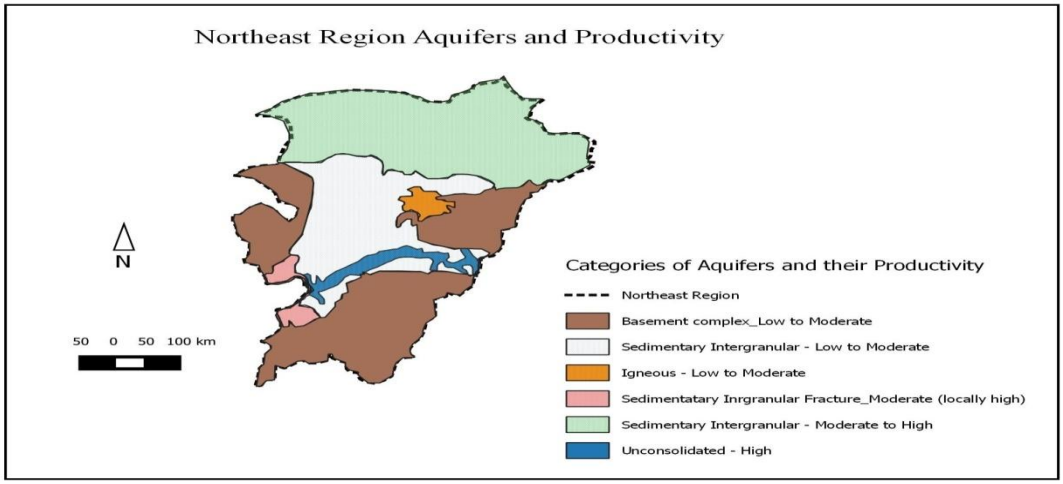
unexplored and has a thickness of up to 200m and largely associated with deeper water level (about 165m around southeast of Bauchi) [12]. Whereas the Chad formation of the North-East region are not sufficiently explored and demarcated, but are basically categorized into three distinct types; the upper, middle and lower aquifers [12]. The upper aquifers are either water table or semi-confined, for instance, areas around Maiduguri has depth limit of 105m) [12]. The middle aquifers is a confined aquifer that has thickness of about 300m and it' distinctively partitioned from the upper aquifer by plastic clay zone of about 150m [12]. Being a trans-boundary aquifer, the middle aquifer recharge falls outside geographical boundaries of Nigeria [15]. And lastly the pre-cambrian formations are characterized as patches of few volcanic plugs, basaltic flows and sedimentary rocks [12].

Figure 2: Simplified Geologic Map of the North-East Region



Source: *Researcher, 2019*

Figure 3: Simplified aquifers distribution of North-East region



Source*: Researcher, 2019*

In the above figure 2 and 3, the aquifers and their respective productivities of the North-East region are categorized into low, moderate and high.

3.4 Accesses and Uses

Within the arid and semi-arid around the World, as the rainfall and surface water sources become less reliable, the demand for groundwater increases astronomically. Various studies such as the Calow et al. [20] and MacDonald and Calow [21] critically observed this pattern across diverse seasons as well as drought years in Ethiopia, Ghana and Malawi and subsequently provided a detail report on the relationships between water availability, access and use, and the causes of source failure. The North-East region also experiences similar pattern of interrelationship. Moreover, some studies also observed that during the drought season surface water and unimproved groundwater sources (shallow wells and small springs) can fail, leaving only those water points drawing from larger groundwater bodies operational [8,12]. Hence larger springs, deep hand-dug-wells and boreholes can provide reliable access to water across seasons, while surface water bodies and unimproved sources become increasingly unreliable. That said, even reliable sources can fail during a drought, though precise causes are not always obvious.

This study also understand that any prolonged pumping of groundwater aquifers within the arid and semi-arid region of Nigeria throughout the day mostly put considerable strain on the groundwater level to depreciate. Consequently, this resulted to the groundwater levels to depreciates into the immediate vicinity of a well or borehole. This is most likely to occur where high demands on a groundwater source are combined with low aquifer permeability and storage [22,23]. However, if the well is allowed to recover, supply can be restored, hence people may begin collecting water at night when demand falls and water levels rebound. In both cases, both the mechanical failure as well as the source-specific drawdown, the key problem is largely lies on the accesses rather than its absolute availability.

3.5 Progresses So Far

Being a country that depends on large food importation, Nigeria's and it' agricultural sector remained largely uncompetitive in the production of major crops when compared with international relative counterparts and markets [10]. Though recently there are drastic reforms on agricultural sector with aim of increasing the country food sufficiency, production as well as attracting indigenous and foreign investments. However, throughout the North-East region, the groundwater resource is considered as the most essential of all natural endowments. Even though, it conditions (in terms of quantity and quality) within the region is threatened by both natural or man-made either directly or indirectly. However, this system is largely affected by issues such as the intensive agricultural production, domestic wastes, industrial activities, unplanned engineering and allied-urban development among others [2]. For instance, recent unsustainable agricultural productions and practices associated with lacking of adequate extension workers and un-mechanized innovations mostly rendered the farmer to resorts to aggressive bush burning and deforestation. These compounding practices resulted to desert encroachment, desertification and catalyzed all forms of erosion which also increases the intensity of the groundwater pollution within the region. Moreover, recent intensive agricultural activities and other allied practices often affect the downstream wetland.

Hence, even the groundwater resource within the North-East region is not evenly distributed both spatially and temporally. Therefore, it is very difficult to establish an apparent boundary between surface water and the groundwater resource within the North-East region of Nigeria. In case groundwater resource management, there are essential needs to mitigate the rate of this region abstraction from the aquifers, so that the rate at which the water level is falling drastically can be tackled. Since throughout this region there are higher exploitations of water resource more than the region recharge from annual conventional rainfall, so, there is need for mitigating the rate of water abstraction, to be less than the amount of recharge to the system. Moreover, there are needs for protecting the lower recharge zones from construction of permanent structures like roads and housing. There is also the need for periodic groundwater resources assessment at specified interval since various methodologies of integrated groundwater resource assessments and models changes over time.

An integrated approach on groundwater potential should always take into account the following attributes; recharge (annual rainfall), aquifer storage (carrying capacity), ease of abstraction of groundwater, portability of water (quality), ecological considerations (Flora and Fauna), and the confidence level of assessment (regionally unified recommended value). Besides the recent undeniable progress in the management of groundwater resources within the North-East region of Nigeria, the management is still facing gigantic challenges. One of the key challenges is the acceleration groundwater development to meet broad coverage targets and ensuring that national benchmarking does not obscure failures in reaching the most difficult areas and vulnerable groups. Moreover, another challenge is the increasing reliability of new sources as well as addressing the under-performance investments in the area.

3.6 Potentials and Opportunities

Nearly half of the populations of Sub-Saharan Africa are in the state of severe and chronic poverty [24]. These mammoth populations lack of access to safe domestic water, and indeed to significant quantities of water for other productive uses defines and contributes to that poverty. Between one-third and one half a billion people in the region rely on unprotected and protected groundwater sources for their domestic water requirements [25]. Further targeted development of groundwater could make a major contribution to the Millennium Development target of halving the proportion of people without access to safe and sustainable water supplies by 2015, as well as contributing significantly to incomes and livelihoods, hence, the North-East region of Nigeria is not an exception. However, the extending accesses to groundwater within this region can be assisted by the following measures;

(a) Significantly reducing the costs of mechanized borehole drilling and construction,

(b) Promoting very low cost drilling technologies in niche hydro-geological environments, preferably through the indigenous private sector, and

(c) Ensuring the functional sustainability of groundwater abstraction points so constructed.

The development of the North-East region' groundwater resource when fully utilizes have capability of reducing the region' high poverty rate. Moreover, the present study didn't undermined the importance of building on users' needs and demands, and also consider the domestic water supply within this region as a permanent service, not merely a short-term issue of construction and accesses targets. The study also championed and prioritized the importance of generating far more detailed hydro-geological understanding in the region, through mapping, monitoring and groundwater data collection. Hence, from the milieu of literatures reviewed at various level as well as numerous contexts, this study understands that water resource management is unpredictable and can easily affects its basic adoption patterns. Though the North-East region groundwater aquifers was never thoroughly studied, however, based on the literatures reviewed, this study also understands there is enormous gap between conclusions of some of these studies and the live experiences of relevant user-groups within the region with regards to the management of groundwater aquifers.

4. CONCLUSION

The present study has concluded that the groundwater aquifers of the North-East region is wholly endowed with budding economic opportunities and worth's that can significantly fast tracked the region's various developmental needs when effectively utilized. These groundwater resource hotspots areas are estimated to be having millions of dollars economic values when efficiently exploited; estimated to be around US $20 to $120 per hectare. The study also delineates that these diverse hotspots areas are ideal for numerous activities such as the agriculture (farming, irrigation and livestock), fishing and fuel wood. The needs for protection of groundwater within the North-East region must remained a priority since most of the populace heavily relied on the region's water resource for daily water supply, domestic uses, developmental projects, agricultural and industrial activities. Conscious exploitation of the region' aquifers (especially the shallow aquifers) must recognize the essential of hydraulics, spatiotemporal availability, quantity and quality stability as well as user-group accessibility. For instance, the variation in water quality is largely a product of anthropogenic activities, while access to water resource is largely determined by individual socioeconomic capabilities.

The existing unregulated groundwater resource exploitation within this region must be discouraged through encouragement of only professional tracking of existing as well as anticipated threats posed by the unsustainable groundwater exploitations and abuses. However, there is also the need for agencies to conducts numerous studies on both human and natural causes of various common resource conflicts. Moreover, there is also the need for remained essential in addressing relevant agencies responses and policy implications regarding this region chronic political instability, conflicts and critical humanitarian emergencies. Even though the North-East region has detailed documented water resource frameworks, policies and targets, however, their applications, implementations and translation to real life situation is very low [3,8,18]. However, the present study also posses' constraints where the aquifers estimations are largely based on interventional and observational limited data, hence, it can also be subject to biases and confounding that may have influences the existing simulation estimates.

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