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USING GRACE AND GLDAS DRIVEN DATA TO ASSESS GROUNDWATER FLUCTUATIONS OF NIGER-SOUTH HYDROLOGICAL AREA OF NIGERIA

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--**ABSTRACT**--

Gravitational Recovery and Climate Experiment's Terrestrial Water Storage and Global Land Data Assimilation System's Surface Water and Soil Moisture including Nigerian Hydrological Service Agency's Groundwater Level were used to assess the temporal groundwater fluctuations of Niger-south Hydrological Area of Nigeria. The study adopted a cross-sectional research design; descriptive and inferential statistics was used for data analysis; Table was used for presentation. The study finds that there is no statistical significant difference between average monthly net recharge and average month storage changes at 95% probability level, it further concluded that the use of these satellites to acquire data and make decision will mark a new era and bring about fewer causalities on natural event(s), and therefore recommended us to take advantage of this free available resource to ameliorate challenges trying to extinct the existence of man from earth surface; therefore, increasing groundwater levels in Niger-south Hydrological Area needed to be properly managed because of rising groundwater flooding.

KEY WORDS: *GRACE, GLDAS, QGIS, Groundwater, Fluctuation.*---

INTRODUCTION

Groundwater plays a critical role in water supply, in ecosystem functioning and human well-being. It is of premium importance owing to its self-filtration, purification and having some properties not possessed by surface water (Oboshenure, Egobueze & Egirani, 2019). Groundwater is the purest and safest form of water on the earth. Groundwater is a vital resource that supplies billions of gallons of water for various uses (Tamunobereton-ari, Omubo-Pepple & Amakiri, 2014). Approximately 2.5 billion people globally depend solely on groundwater resources to satisfy their daily water needs, and hundreds of millions of farmers rely on groundwater to sustain their livelihoods and contribute to the food security of many (UNESCO, 2012), a large number of people depends on groundwater to satisfy their drinking water need globally. Groundwater reportedly provides drinking water to at least 50% of the global population and accounts for 43% of all water used for irrigation, and sustenance of the base flows of rivers and important aquatic ecosystems (Adesuyi, et al, 2015).

Groundwater is the portion of precipitation that percolates into the soil and moves downwards to fill cracks and openings in rocks and sand, global total water situated as ocean water is 96.5%, about 0.9% of which is saline water outside ocean in other water bodies, only 2.5% of the global total water is fresh water out of which only 30% of these proportion is stored underground as groundwater, where 68.7% is stored in glaciers and 1.2% are available as surface and other fresh water (NASA ARSET webinar, 2020).

The age of groundwater is a function of frequency of extraction from underground storage system; it ranges from few months to million years (Gleeson et al, 2016). They estimate that total groundwater volume in the upper 2km of continental crust is approximately 22.6 million km^3, of which 0.1-5.0 million km^3 is less than 50 years old, meaning that the rate of extraction is alarming and there is need to monitor the fluctuation of these scarce resources against drought occurrences.

Nigeria Water Resources Management is the sole responsibility of The Federal Ministry of Water Resources whose function includes large water resources developmental projects and water allocation between states (Idu, 2015), handling the affairs of 16 parastatals consisting of 12 River Basins Development Authorities and 4 other Agencies, Commission and Institution of which Nigeria Hydrological Services Agency is a part. The first two River Basin Development Authorities was created in 1973 by Decree 32 and 33 of 1976, 9 other River Basin Development Authorities were also established based on decree 25 of 1976. In the later years (1984) Niger River development Authority was split into two other parastatals making it up to 12 River Basin Development Authorities (JICA, 2014). The Nigerian Hydrological Services Agency was created through Gazette of Federal Republic of Nigeria number 100, volume 97 of 31st August, 2010; with a mandate of maintaining hydrological stations nationwide. Their functions involve carrying out groundwater exploration as well as assessing Nigeria surface and groundwater resources in terms of quality, quantity, distribution and availability over space and time. For effective management of Nigeria water resources, Nigeria space were divided into eight hydrological areas in accordance with the river basins of the country; the present researcher chose to focus on Niger-south Hydrological Area of Nigeria due to its importance in Nigeria water resources, agriculture and overall economic development of the region. Niger-south Hydrological Area of Nigeria is named after the mighty Niger River which transverse through this area along with the tributaries of Benue River. The area comprises of numerous creeks and swamps of complex networks of freshwater bodies forming Niger Delta which is the world's largest River Deltas, hence the need for the present study.

STATEMENT OF THE PROBLEM

The increase in population has led to decrease in the amount of available good quality water resources required to meet up with the competing demands for water allocation towards industrial, agricultural and domestic uses (Qadir & Oster, 2004). The population of the study area has grown over the years from 28.9 million people in 2006 to about 39.3 million people in 2016, so is the demand of good quality water required to sustain the population (NBS, 2020).

According to National Water Resources Master Plan completed in 1995, Nigeria's groundwater resource is estimated at about 52 billion cubic meters of replenishable yield per year (Maduabuchi, 2014). This implies that the nation's groundwater resource is abundant and of good quality. More than 40 percent of the Nigerian population relies on groundwater for her public water supply. Also, more than 40 million people including rural dwellers get their drinking water from domestic wells (Nwankwoala, 2016). Many cities, towns and villages in Nigeria rely on groundwater for their water supplies owing to its abundance and stable quality. Groundwater is extracted through hand dug wells and borehole systems in many settlements in south-east and south-south Nigeria resulting to the abundance of good quality of groundwater resource. Consequently, there is high dependency on untreated groundwater extracted through hand dug wells and borehole systems (Ocheri, 2006; 2010). However, the quantity of groundwater is increasingly being threatened as a result of over exploitation and population increase. It is on this premise that the present study attempts an assessment of the temporal groundwater fluctuations in Niger-south hydrological area of Nigeria.

OBJECTIVES OF THE STUDY

The specific objectives are to:

i. Determine the monthly groundwater storage changes within Niger-south hydrological Area of Nigeria over the period of 13 years (2010 to 2022)?
ii. Examine the average monthly storage and recharge of groundwater in Niger-south hydrological area of Nigeria
iii. Predicts the relationship that exist between GRACE estimated groundwater storage and the Nigerian Hydrological Service Agency's observed groundwater level within the study period.

RESEARCH QUESTIONS

The following research questions were asked to guilde this investigation:

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i. How does the groundwater storage change monthly within Niger-south hydrological Area of Nigeria changes over the period of 13 years (2010 to 2022)?
ii. What is the average monthly storage and recharge of groundwater in Niger-south hydrological area of Nigeria?
iii. What the relationship between GRACE estimated groundwater storage and the Nigerian Hydrological Service Agency's observed groundwater level within the study period?

RESEARCH HYPOTHESES

The following null hypotheses were stated:
H_{01}: There is no statistically significant relationship in the monthly rate of groundwater storage in Niger-south hydrological area of Nigeria over the period of January 2010 to November 2022.
H_{02}: There is no statistical correlation between monthly groundwater storage and net recharge within the study period.
H_{03}: Statistically, there is no relationship between GRACE estimated groundwater fluctuations and the Nigerian Hydrological Service Agency's observed groundwater level within the study period.

THEORETICAL FOUNDATION

Remote Sensing Theory

Remote sensing theory is a science that has established a theoretical basis for measuring earth surface properties using reflected, emitted, and scattered electromagnetic radiation. The National Aeronautic Satellite Agency's mission (NASA, 2020) posits, this theory develops the methodologies and technical approaches for analysis and interpretation of such measurements.

The Remote Sensing is basically a multi-disciplinary science which includes a combination of various disciplines such as optics, spectroscopy, photography, computer, electronics and telecommunication, satellite launching and others (Shefali, 2003). All these technologies are integrated to act as one complete system itself, known as Remote Sensing System. There are a number of stages in a Remote Sensing process, and each of them is important for successful operation.

Stages in Remote Sensing

- Emission of electromagnetic radiation, or EMR (sun/self- emission).
- Transmission of energy from the source on the earth surface.
- Interaction of electromagnetic radiation with the earth's surface.
- Transmission of energy from the surface to the remote sensor.
- Sensor data output.
- Data transmission processing and analysis.

REVIEW OF LITERATURE

Surface Water Changes and Soil Moisture Changes of GLDAS

Surface water and soil moisture changes are the essential components for groundwater storage, and they can be measured accurately by the in-situ method. But for the large-scale basin it is not possible to achieve, so for large scale global hydrological changes Global Land Data Assimilation System (GLDAS) perform better than stations data (Rodell et al, 2007, Swenson and Wahr, 2006a, and Houbong et al, 2012). Global Land Data Assimilation System (GLDAS) of National Aeronautical Satellite Agency (NASA) aims to utilize advanced surface modeling and data assimilation methods to capture satellite and terrestrial observation data products to produce flow fields and optimal land surface status (Rodell et al., 2007). Global Land Data Assimilation System implements multiple terrestrial models (off-line) through Land Information System (LIS) which integrate large amounts of data based on observation and achieve a high resolution (2.5^0- 1km). Global Land Data Assimilation System (GLDAS) driven models are used to observe the surface water and soil moisture at different time intervals (daily, 3days and monthly), for the terrestrial water storage estimation of which Groundwater storage (GWS), Surface Water or runoff (SW), Snow water equivalent (SWE), and Soil moisture (SM) are the major contributors. While the spatially observed soil moisture does not presently match the observation from the four hydrological models; Xiao, et al. (2023) concluded that estimation from these models would not affect the groundwater storage estimation.

Total Water Storage (TWS) Data Collection and Processing from GRACE and GRACE-FO Level-1
The first level Gravity Recovery and Climate Experiments (GRACE) satellite data from University of Texas Center for Space Research (Akhtar et al, 2022) and Jet Propulsion Laboratory (Ali et al, 2022) data processing center were employed from January 2003 to July 2021 by Aref, Abdulhalim and Abdullah (2022) to study Groundwater storage changes estimation using the gravity recovery and climate experiment's satellite data in Helmand River Basin. According to their research, first level Terrestrial Water Storage (TWS) data is available at no cost in the platform (https://grace.jpl.nasa.gov/data- analysis-tool/); also the Helmand River Basin University of Texas Center for Space Research and Jet Propulsion Laboratory data ($1^0 \times 1^0$) have some time irregularities for several months. However, one of the advantages of Gravity Recovery and Climate Experiments satellite data is its complete spatiotemporal data over a large area provision. More so, despite its low resolution, it has the advantage of recording changes in total or part Terrestrial Water Storage (Bhanja, et al., 2016). In their work, they use Terrestrial Water Storage (TWS) data was converted to point data by utilizing Geographic Information System (GIS) software, then Point data was interpolated twice and consequently downscaled.

Global Land Data Assimilation System Data Collection and Processing
Since parameters of soil moisture, surface water and water equivalent to snow and glaciers are integral elements in computing groundwater storage changes, albeit the accurate measurement of these parameters or obtaining these data in spacious areas is challenging. As a result, Global Land Data Assimilation System large-scale hydrological changes are better than other devices.

The Global Land Data Assimilation System (GLDAS) of National Aeronautical Satellite Agency (NASA) aims to employ advanced surface modeling and data correlation methods to capture satellite and terrestrial observational data outcomes to generate flow fields and optimize ground surface conditions (Rodell, et al, 2007). In his research, The Global Land Data Assimilation System model soil moisture to a depth of 2 meters with surface water and the Global Land Data Assimilation System (Amin, Khan, and Jamil, 2019) model, both with one-degree accuracy and the amount of water storage in plants, plus water equivalent to snow, is used. The data is available in this open source: (https://giovanni.gsfc.nasa.gov/giovanni/).

Review of Groundwater Related Literatures
Gravity Recovery and Climate Experiment (GRACE) and Gravity Recovery and Climate Experiment follow on (GRACE-FO) are twin satellites in polar sun synchronous orbit at altitude of 485km which are loosely controlled and separated by 220km apart (Wei, 2018). Gravity Recovery and Climate Experiment's was launched on March 17th 2002 and its program ended on October 12th 2017. Due to its relevancy Gravity Recovery and Climate Experiment Follow On was launched on May 22nd 2018 and its mission is on till date. The two satellites mission were launched by the combined effort of National Aeronautics and Space Administration (NASA) and German Aerospace Center or Deutsche Zentrum für Luft und Raumfahahrt (DLR), and the satellites provide direct observation of earth gravity field and its temporal variation with utmost accuracy. Gravity Recovery and Climate Experiments has been used to track groundwater storage variation in a number of large areas (Llovel et al, 2010; Tarul et al, 2013, Joodaki et al, 2014) land mass greater than 150,000km^2 thus lower resolutions.

Similar to Gravity Recovery and Climate Experiments is another component of National Aeronautical Satellite Agency's remote sensing tool known as Hydrology Data and Information Services Center (HDISC) data called Global Land Data Assimilation System (GLDAS), which ingests satellite and ground-based observation data products, using land surface modeling and data assimilation techniques to generate series of land surface state (e.g. soil moisture and surface temperature) and flux (e.g. evaporation and sensible heat flux) since 1979. The data is stored in different formats with the goal to develop a portal that will support weather and climate forecast, water and energy cycle research. This present study will apply both Gravity Recovery and Climate Experiments and Global Land Data Assimilation System data base to investigate the temporal fluctuation of groundwater of Niger-south hydrological zones of Nigeria at higher resolution.

Relationship between GRACE and GLDAS
Previously, many scholars have stated the relationship that exists between Gravity Recovery and Climate Experiments (GRACE) and Global Land Data Assimilation System (GLDAS). This relationship is a function of atmospheric condition, geographic location or region of the basin under investigation. For instance, Mo, et al. (2016); Chen, et al.

(2019); Rahaman, et al. (2019); Li, et al. (2019) and Ali, et al. (2022), incorporated both Gravity Recovery and Climate Experiments (GRACE) and Global Land Data Assimilation System (GLDAS) in their works to accomplish their desired result. And they show that terrestrial water storage is the sum of soil moisture in all layers, accumulated snow, and plant canopy surface water, total precipitation is the sum of rainfall and snowfall and the total runoff is the sum of subsurface runoff and surface runoff.

The mathematical relationship (table 1-3) between Gravity Recovery and Climate Experiments data (TWS) and Global Land Data Assimilation System (SM and SW) data are stated below: Deriving from water budget equation which states that the water inflow to any system or area is equal to its water outflow and discharge in storage during time interval.

P + ET + Q = total water balance (TW) (1)

Where, P = Precipitation,

ET = Evapotranspiration

TW = Terrestrial or Total Water Balance and

Q= Change in water storage in the watershed.

Change in water storage (Q) include: surface water (snow water equivalent, soil moisture and reservoirs), and sub-surface water (root zone moisture, groundwater component). Therefore, the change in water storage in the watershed will be subdivided into components of soil moisture (SM), snow water equivalent (SWE), surface water (SW) and Groundwater (GW);

So, TWS = SM + SW + GW + SWE (2)

However, in study areas like Nigeria, snow water equivalent is not considered due to the fact that Nigeria is not subjected to snow accumulation activities (Bhanja et al, 2016). Establishing that these hydrologic parameters were obtained in anomalies or continuous changing states. Therefore,

$\Delta TWS = \Delta GW + \Delta SM + \Delta SW + \Delta SWE$ (3)

Where, ΔGW = change in groundwater (unknown)

ΔTWS = change in terrestrial water Storage (GRACE)

ΔSM = change in soil moisture (GLDAS)

ΔSWE = change in snow water equivalent (GLDAS)

ΔSW = change in surface water storage (GLDAS)

METHODOLOGY

The Study Area: This section examines the geography of the study area in details. The geography examined includes: location and extent, geology and soil, relief and drainage, weather and climate, vegetation, socio-economic activities as well as population. The study area lies between latitude $4^0 30^I$ to $7^0 45^I$ north and longitude $5^0 30^I$ to $7^0 30^I$ east. According to Nigerian Hydrological Services Agency (NIHSA), Nigeria space is divided into eight hydrological areas namely: Niger-north, Niger-central, Niger-south, West littoral, East littoral, Lake Chad, Upper Benue, and Lower Benue Hydrological Areas (Fig.1)

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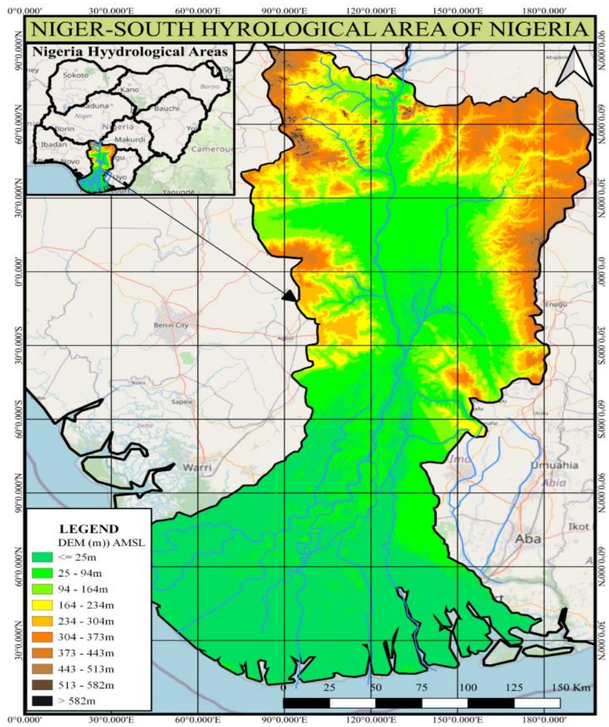

(Fig. 1: Niger-south Hydrological Area of Nigeria)

Descriptive and inferential statistics was used in the course of data analysis. Tables and charts were used to present the data. Quantum Geographical Information System (QGIS) version 3.18 Zurich which is the current edition launched on March 2021 was used to clip shape-files and to convert all parameters to a common unit and also estimate temporal groundwater fluctuations. Further analysis was done through Microsoft Excel 2010 edition and Statistical Package for Social Sciences (SPSS) version 22; for graphs, mean and standard deviation, correlation coefficient and regression

DATA PRESENTATION

Table 1: Estimated Groundwater Storage (1000mm) of the Study Area Jan. 2010 to Nov. 2022

GWS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Annual	Avg
2010	72	69	67	66	67	70	74	76	78	79	78	75	870	72
2011	71	67	67	65	67	68	70	75	78	78	77	74	856	71
2012	70	67	67	66	66	68	73	76	78	78	78	75	862	72
2013	71	69	67	66	67	69	72	73	75	76	76	74	856	71
2014	71	69	67	67	68	70	72	74	77	78	78	76	867	72
2015	71	68	67	67	67	68	71	74	76	77	77	74	858	71
2016	69	67	66	66	66	69	72	74	76	77	76	73	850	70
2017	70	68	66	65	66	68	71	73	75	76	75	73	846	70
2018	70	67	66	65	65	68	72	74	77	78	77	75	855	71
2019	71	69	68	68	69	71	74	76	78	79	79	77	881	73
2020	73	69	67	67	67	69	74	75	76	79	78	75	871	72
2021	72	69	68	67	67	69	72	74	78	78	77	75	867	72
2022	73	69	68	67	69	71	74	76	77	79	75		798	73

Source: Researcher' Concept 2023; as extracted from Giovanni files using Excel Pivot table

DATA ANALYSIS

Decision Rule: Reject null hypothesis (H_0) and accept alternate hypothesis (H_1), if correlation result shows * * (double star), it indicates significant at 0.01 probability value (PV<0.01). Similarly, * (single star) indicates it's significant at 0.05 probability value (PV<0.05). But if without * (star) it means there is no significant; therefore, reject null hypotheses. Also, 0.1 and above = positive relationship also -0.1 and below = negative relationship while 1 is a perfect relationship. Based on the hypotheses were stated as above.

H_{01}: we used the monthly groundwater storage estimates from GRACE terrestrial water storage (table 1) to make justice to hypotheses 1.

H_{02}: This hypothesis involves the testing of the significant difference between monthly net recharge and monthly groundwater storage changes; this involves two sets of variables:

1 Net recharge which in this part of world is known as rainfall.

It is obvious that the only source of groundwater recharge in Niger-south hydrological area of Nigeria is through rainfall. Hence, we assumed that all the rainfall serves as recharge to groundwater of the study area.

2. Average monthly storage changes which is the groundwater as estimated and presented as graph in fig. 1

To test the hypothesis two, we use same data we applied in hypothesis one on monthly bases thus; our monthly recharge was plotted against our monthly groundwater storage as our storage, and we used Pearson's Correlation Coefficient to ascertain the relationships that exist between recharge and storage.

H_{O3} This hypothesis involves the testing of the validity of the satellite obtained data use to carried out our research, the groundwater storage data and observed groundwater level data will be compared to ascertained the difference that exist between them.

To test the hypothesis three, we use our monthly groundwater level and it was plotted against monthly groundwater storage to ascertain the relationship that exist between estimated groundwater storage and recorded groundwater level.

RESULTS

The result of our first hypothesis indicates that there is no statistically significant difference in the monthly groundwater storage in Niger-south hydrological area of Nigeria over the period of January 2010 to November 2022. Furthermore, a strong positive relationship exists within these years.

The second hypothesis shows there is no statistically significant difference between average monthly net recharge and average monthly storage changes at 95% probability level. Furthermore, there is a weak positive relationship that exists between recharge and storage.

While the third hypothesis proves that there is statistically significant relationship between groundwater storage estimated from GRACE and groundwater level recorded by NIHSA in Niger-south Hydrological Area of Nigeria between 2010 and 2022. Also, correlation coefficient of 0.982 indicates that a strong positive relationship exists between groundwater storage and groundwater level.

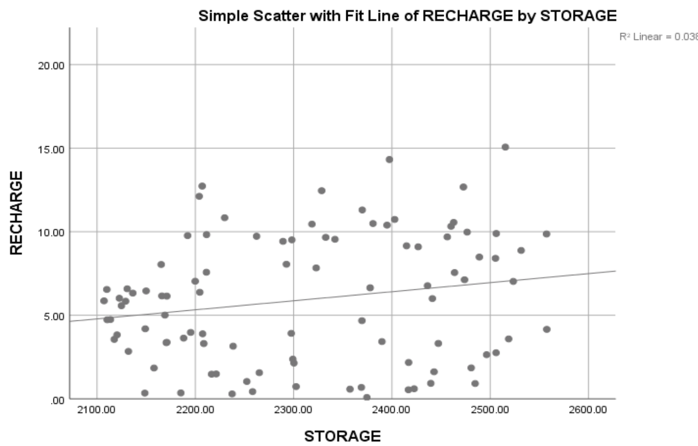

Fig. 2: Scatter Graph of Rainfall Recharge against Groundwater Storage of Niger-South Hydrological Area of Nigeria

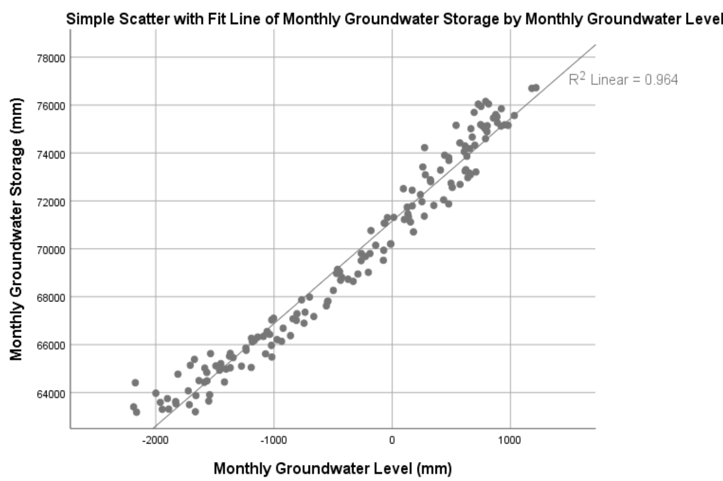

Fig. 3:Scatter Graph of Monthly Groundwater Storage against Groundwater Level of Niger-South Hydrological Area of Nigeria

DISCUSSION

The result of hypothesis one (Ho_1), which compared groundwater estimated from each year against the other years using correlation matrix; uphold alternate hypotheses (H_1). Therefore, we stated that there is statistically significant relationship in the monthly groundwater storage in Niger-south hydrological area of Nigeria over the period of January 2010 to November 2022. Furthermore, a strong positive relationship exists on monthly groundwater within the studied years. Meaning there is a smooth response of groundwater to precipitation (rainfall) signals over the study area (Kumar et al, 2016).

The result of hypothesis two (Ho_2) shows that there is no statistically significant difference between average monthly net recharge and average monthly storage changes of Niger-south hydrological Area of Nigeria. The coefficient of determinant further reveals that only 3.8% of the Average monthly rainfall recharges groundwater storage which affirms the works of Schict and Walton (1961) that a time lag occurs between the arrival of water during a recharge event and the redistribution of that water to the other components.

Hypothesis three (Ho_3) which validate our source of data compared estimated groundwater storage driven from GRACE and NIHSA's recorded groundwater level states that there is no relationship between GRACE estimated groundwater storage fluctuations and the Nigerian Hydrological Service Agency's observed groundwater level within the study period and the result shows that there is statistical significant relationship between groundwater storage estimated from GRACE and groundwater level recorded by NIHSA in Niger-south Hydrological Area of Nigeria between 2010 and 2022. Also, correlation coefficient of 0.982 indicates that a strong positive relationship exists between groundwater storage and groundwater level as coefficient determinate (R^2 = 98%) further support the outcome. Thus, direct proportional relationship exists between the two sets of data.

CONCLUSION

From the analysis above we can deduce that application of this methodology that involves the use of satellite to acquire data to make decisions on the phenomena under investigation will enable man to predict the possible outcome of an event before its occurrence. So, using such decision-making tool will mark a new era of survival or fewer casualties on natural event.

Also, that GRACE and GLDAS data were able to show the natural periods of drought and floods in the study area. Therefore, developing a model that incorporates this data to project the future events of drought and flooding is essential for decision makers not only for the sustainability of the study area but the world at large.

RECOMMENDATION

The signaling function of plans and planning must be strengthened. Heavy rain hazards and risk map should be provided as new protection standards. More so, protection targets for critical and sensitive infrastructural needs should be defined and awareness of unavoidable residual risk needs to be raised. Therefore, intensive preparation of civil protection and water management is highly recommended for rare flash flood and heavy rain so as to improve the management of these events.

It is recommended for us to take advantage of this free available resource to ameliorate challenges trying to extinct the existence of man from earth surface; therefore, increasing groundwater levels in Niger-south Hydrological Area needed to be properly managed because of rising groundwater flooding.

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