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MODELING OF GROUNDWATER LEVEL IN RIVER MALLAM SULE CATCHMENT AREA, NIGERIA

*Kumo Hassan Ali

Department of Quantity Surveying, Faculty of Environmental Studies, Kaduna State University, Kaduna, Nigeria

*Corresponding Author Email Address: halikumo@gmail.com

ABSTRACT

The demand for water has increased over the last few decades, due to increase in population, social and economic development in different part of the World. The drying up of boreholes and wells worsens the problem of water scarcity in Yobe State because of the high demand for water. The study aimed at stimulating and predicting the groundwater level in River Mallam Sule catchment Area, Nigeria. Resistivity data, Gravity Recovery and Climate Experiment (GRACE) data, Digital elevation model, stream flow data, and Land Use Land Cover map. Soil Water Assessment Tool (SWAT) was used as a model to simulate and predict the groundwater level. It was calibrated successfully. Descriptive and Mann Kendall trend was used to compute trend in the variability of groundwater. The result of the study shows the level of surface water anomalies was lowest in 2008 and highest in 2015. Similarly, the level of soil moisture was lowest in 2018 and highest in 2004, terrestrial water storage was lowest in 2008 and highest in 2014 while groundwater level was lowest in 2006 and highest in 2008. The calibrated model was used to predict the future scenario of groundwater in the study area for 2030s, 2060s and 2100s, using 1981 to 2020 as the base line, the calibration was successful. The result of inter decadal trend analysis of projected groundwater from 2020 -2050 shows a negative trend from 2020-2049 and a positive trend in 2050. The study concluded that the temporal variation of groundwater, surface and terrestrial water storage anomalies has moderate variability with positive trend, while soil moisture and groundwater anomalies shows a negative trend, this implies that there is a decrease in the soil moisture and groundwater. The study recommended that there should be alternative source of water to reduced sustained pumping of groundwater which lead to the decline in groundwater.

Keywords: Resistivity data, Gravity Recovery and Climate Experiment (GRACE) data, Digital elevation model, stream flow data, and Land Use Land Cover map. Soil Water Assessment Tool (SWAT)

INTRODUCTION

Water is an important natural resource that virtually all human activities depend on its adequate supply (Simon et al., 2021). It plays an important role in the world economy because it is an essential resource for industrial growth and agricultural development (Isa et al., 2023). Water has two sources which are surface and underground source. Surface water is water that is found on the surface of the earth which includes rivers, lakes streams, reservoirs, and wetlands (Alwreikat & Lananan, 2022). Groundwater is any water found under the surface of the earth. Groundwater is pumped from its source which is known as the aquifer to the earth's surface for various domestic, agricultural, and industrial uses (Carrard et al., 2019). For example, about 60% of the population in Nigeria is dependent on groundwater for their domestic and industrial uses. About 37% of boreholes in the country are not working effectively as a result of decline of groundwater (Ezechinyere & Stanislaus, 2023). In Nigeria among the 37 million Km^3 of the drinking water, about 8 million Km^3 is found in groundwater. Groundwater provides 25% of the freshwater used in the United States, which uses for irrigation, domestic uses and about half of the population of United State dependent on groundwater (Karandish et al., 2025). Also in the arid areas, high demand for groundwater and slow replenishment provide challenges for sustainable groundwater management (Alao et al., 2024). Similarly, in South Africa, 55% of boreholes shows a drastic decline in water level, and 63% of boreholes recorded low water level from 2015 to 2019 and the decline of this is a serious problem (Taonameso et al., 2019). Groundwater is the main source of water for domestic and other industrial uses in the Nigerian sector of the Chad Basin and it has been established that groundwater is declining in the entire region of the Chad Basin (Vassolo et al., 2024). The study area falls within the semi-arid region of northeastern Nigeria which is characterized by low rainfall (500-700 mm/annum), and high evaporation (> 2000 mm/annum) the recharge for groundwater will defiantly be low (Babati et al., 2021). The demand for water increased over the last few decades, due to increase in population, social and economic development in the region, a lot of pressure is on the groundwater through frequent pumping of the water from the aquifer (Sherif et al., 2023). Sustained groundwater pumping is a factor that declines the amount of underground water (Dangar et al., 2021). The drying up of boreholes and wells worsens the problem of water scarcity in Yobe State because of the high demand for water. More so, hand-dug wells and boreholes constructed by individuals, government and non-governmental organizations are drying up eventually due to poor construction and also lack of information on groundwater before groundwater exploration (Babati et al., 2021). This has been attributed to poor groundwater assessment. Yobe State is expressing an increase in aridity which accounts for the shrinking of water bodies in the region. This has made accessing of underground water a better alternative.

Preservation and conservation of the groundwater is required. This can be achieved through monitoring which required simulation, and predication of groundwater at all level. Predication and simulation of groundwater requires a continues groundwater data which is inadequate in the study area but with the development of Gravity

Recovery and Climate Experiment (GRACE) which was launched in March 2002, data is now available for use. GRACE has the capacity to offer an operational product in the form of global gravity fields on a monthly basis. After several gravity effects have been released defined examinations of the time-series global gravity field fluctuations make the spatial monitoring of water storage changes at large scale such as basins possible (Ahmed et al., 2014). Through 19 years of establishment, GRACE satellite data processing and corresponding TWS retrieval algorithms are enhanced continuously. They are able to detect the changes of TWS within the accuracy of 1.5 cm on a wide range of spatial scales and seasonal time scales. GRACE offer other procedural approaches for the appraisal of glaciers, surface snow, soil water, surface water, groundwater, evaporation, and other components in the terrestrial hydrological system (Chen et al., 2014). GRACE data has the capacity to give continues data of groundwater from 2002- to data. Soil Water Assessment Tool (SWAT) was adopted as a model, it has been successfully used to model the surface water availability and variability in basin scale especially in the watershed where there is no stream gauge unlike other numerical models, it also has the capacity to predict and simulate particular or multiple aquifers (Chen et al., 2022). Other data required for the model can be provided through the use of remote sensing and geographical information system. Remote Sensing (RS) technology produces a genuine source of information in classifying, identifying, mapping, and planning of natural resources (Musa et al., 2022). The study aimed at simulating and predicting the groundwater level in River Mallam Sule catchment Area, Potiskum, Yobe State, Nigeria.

MATERIALS AND METHOD

Study Area

The study area is located along Kano- Maiduguri federal highway. It is located between latitudes 11°03' and 11°30' North of the Equator and between longitudes 10°50' and 11°51' East of the Greenwich Meridian. Its distance by road from the State capital is about 98 kilometers west (Fig 1) . The study area is located in the tropic which has two sessions which are; wet and dry seasons. Wet season is distinguished with the moist maritime South- westerly monsoon which emanated from the Atlantic Ocean and dry season is distinguished with the dry continental Northeast trade wind which emanated from Sahara Desert (Babati et al., 2021). Rainy season commences in the month of June and end in the month of September with the annual rainfall ranges from 500mm – 700mm. There are no precipitations from January to March in the study area (Ogungbenro & Morakinyo, 2014). The study area lies within the wet and dry Sudano-Sahelian Savanna belt of Nigeria. The Vegetal cover is sparse as the grass grows nearly at the base leaving bare surfaces in between. The grasses in the Sudano-Sahelian Savanna belt are short in height (0.5m to 1.0m) (Arogundade et al., 2020). The study area lies within the Nigerian sector of the Chad Basin. The area is a part of the sediments of the Chad Basin comprising such rock types as sand and sandstone, clay/shale intercalations that formed the Chad Formation which dips concentrically at about 1.5m/Km (Nwankwo et al., 2010). The soil of the study area is originated from drift materials which are mainly silt clay. The soil has poor capacity to retain water, the soil in the study area is mainly brown and reddish-brown soils. Calcium carbonate concentration is present at about a meter depth(Yusuf et al., 2022). The soil has low organic content but the organic matter is highly humified and well allocated in the profile(Boboye et al., 2018).

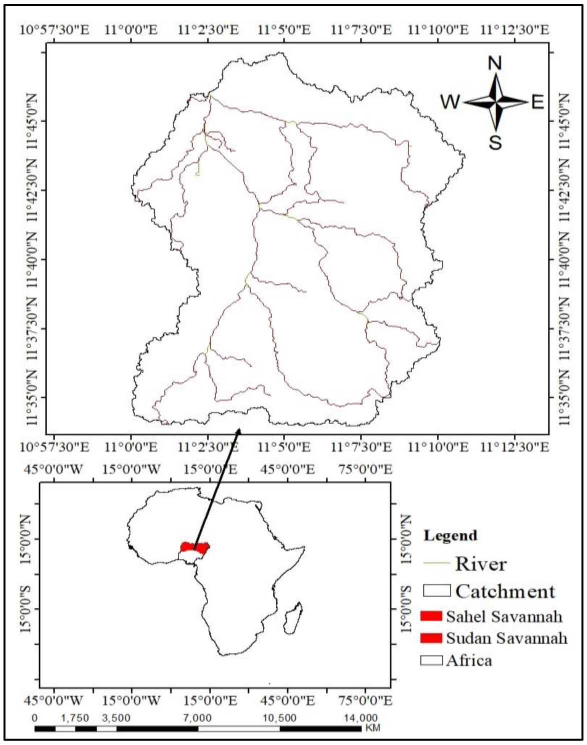

Figure 1: Map showing study area

i. Global positioning system (GPS) was used for accurate location of the sampling points of boreholes and subsequently used the calibration. Coordinate was imported in to Microsoft excel, it was arranged accordingly and converted to decimal degrees then saved as Command Delimited and then imported in to the GIS environment for further use.

ii. Resistivity of boreholes was obtained from Africa development bank, Yobe State. Resistivity data was imported in to Microsoft excel, saved as Command Delimited and then imported in to GIS environment. Join and relate tool were used to link the resistivity data with the coordinates.

iii. Gravity data was obtained from the GRACE website, it was used for assessment of spatial distribution of ground water level and compared with the numerical simulated groundwater.

iv. Climate data was obtained from Nigerian Meteorological

Agency, it served as an input used to build the ArcSwat model. Climate data was subjected to clipping, missing value, outlaying and normalization. The missing values were test in order to ascertain the completeness of the data for further analysis. According to World Meteorological Organization (WMO) standard, it is not recommended to fill more than 10% of missing data. Due to the scarcity of data, a threshold of 15% was used. Therefore, the Missing data in climate variable will be filled using the ordinary least squares (OLS) methods.

v. Stream flow data was obtained from Princeton climate analytics (PCA) website, it served as an input to the model. Stream flow data was screened for possible outliers that could be attributed to errors in transcribing the data. Missing data in stream flow was filled using the ordinary least squares (OLS) methods.

vi. Soil moisture was obtained from global land evaporation Amsterdam model version 3.3, it was used to extract groundwater level from GRACE data.

vii. Landsat Imagery was used to obtained the land use and land cover change from 2002 – 2019.Landsat imagery was subjected to co-registration, conversion to radiance, solar correction, and atmospheric correction. Radiometric and geometric restoration processes were applied to restore image from errors. Landsat imagery has limitations, it has thirty meters resolution which does not give accurate results especially when conducting land use, land cover analysis. Within a pixel, any class with a dominant spectral reflectance will cover the entire pixel (Mas & Soares de Araújo, 2021).

Temporal variation of SWE, SMC, SWS and GWS

Gravity data was subjected to clipping, sub-setting and as well as geometry correction. GRACE file consists of 1-degree grid resolution file (360 x 180 degrees) for the entire globe was downloaded. To extract the area of interest, GRACE ASCII file was opened in ArcGIS and overlaid on the basin boundaries. The Identify tool in ArcGIS was used to define the GRACE values over the study area. Then, opened the GRACE file in Microsoft Excel and defined the boundaries of the area by known values. To derived ∆GWS

$$\Delta TWS = \sum_{i=1}^{n} \Delta HC_i$$

$$\Delta HC = \sum (\Delta SWE, \Delta SMC, \Delta CWE, \Delta SWS, \Delta GWS)$$

Where ∆ TWS = change in total water storage
∆ SWE = snow and ice
∆ SMC = soil moisture
∆ CWE = water equivalent in canopy
∆ SWS = surface water
∆ GWS = ground water

Each component can be derived from the above equation by making the component of interest as the subject of the formula. Considering the nature of Sub-Saharan region of Nigeria, especially in the study area which is located in Sudan-Sahel region where vegetation is scattered and snow and ice are absent. The total water storage can be derived as:

$$\Delta TWS = \sum_{i=1}^{n} (\Delta SMC, \Delta SWS, \Delta GWS)$$

To derived the ground water anomalies

$$\Delta GWS = \Delta TWS - \sum_{i=1}^{n} (\Delta SWS, \Delta SMS)$$

The data was on monthly basis, which was used to find the annual average groundwater level. The annual mean ground water level sorted from monthly gravity data was subjected to coefficient of variance, mean and standard deviation. Time series was applied to determine the trend. Similarly, Mann Kendall trend test was used to determine the trend of the groundwater level. If the Kendall is positive, it means increased trend while if it is negative mean decreased. The significant of the trend was ascertained at significant level 0.05. Also Seasonal and Long term variability was assessed using coefficient of variance, mean and standard deviation. Time series analysis was used to analyses the trend.

Coefficient of variance, mean, standard deviation, and Mann Kendall trend was computed based on the value of the location, from GRACE data.

Simulation and prediction of groundwater

Soil Water Assessment Tool (SWAT) was used in the study, because it has been successfully used to model the surface water availability and variability in basin scale especially in the watershed where there is no stream gauge. River MallamSule Catchment boundary was delineated using SRTM DEM (90m resolution), while be AsterDEM (30m resolution) was used for drainage network in Arc SWAT 2012. Sub basin and their topographic characteristic was generated.

The defined groundwater head and flow at the catchment scale required a high number of marshes. Thus, a grid of 1m x 1m cells was used to cover the area of 280.11km^2. The DEM of the defined catchment was used as the top of the grid, and the coverage of the model top was extended to all cells in order to differentiate the active cells from the inactive cells. Whereby grid within the catchment refers to as active cells and the inactive cells are the grid outside the catchment boundary. Due to unreliability and continue information of pumping tests the aquifer was assumed to be a single layer aquifer having a vertical recharge with top soil, lower weathered and fractured rocks. The bottom of the aquifer was assumed to be impermeable bedrock. The numerical model therefore was used to simulate the groundwater flow under the current stress conditions. The land-use map, soil and stream flow data, were used as input, and hydrological response unit definition was determined in the model based on these data. The land-use map as a base land use/land cover map. Meteorological data was loaded as an input with the help of the weather input interface. 30-years climate data (1980-2019) was used to build initial model. The model setup for the simulation period of 1980 and 2015 (35 years). Finally, the model was set for run for the simulation, calibration, and validation analysis respectively.

The sensitivity value obtained from the Kamadugu watershed was used for SWAT model calibration and validation. After the SWAT model was developed and was run for the first time, the sensitivity value was imputed in to the SWAT model and then run, this is where the calibrated and uncalibrated value was compared due to lack of observed data in the study area. The seventeen-sensitivity value is adopted by the researcher due to the fact that the area is same, they have same characteristics of geological formation, same soil formation and similar pattern of land use/land cover.

The calibrated model which follows certain steps in objective three was used to predict the future scenario groundwater in the study area for 2030s, 2060s and 2100s. As such 1981 to 2020 was used as base line. Thus analysis of variance was used to show extend of the future scenario variation from the baseline.

Variability of surface water, soil moisture, terrestrial water and groundwater anomalies.

Variability of surface water, soil moisture, terrestrial water, and groundwater anomalies was shown in Table 1. The average value for surface water anomalies is 50.6189, soil moisture is 59.7324, terrestrial water storage anomalies is 33.8934 and groundwater storage anomalies is 49.8821 respectively. The variance of surface water anomalies is 891.2612, 639.4970, 964.1212, and 976.6212 for soil moisture anomalies, terrestrial water storage anomalies and groundwater storage anomalies respectively. More so, the standard deviation for surface water anomalies is 29.8540, 25.2883, 31.0503, 31.2509 for soil moisture anomalies, terrestrial water storage anomalies and groundwater storage anomalies respectively. Finally, the coefficient variation for surface water anomalies is 0.5711, 0.4099, 0.8870 and 0.6066 for soil moisture anomalies, terrestrial water storage anomalies and groundwater storage anomalies respectively.

Anomalies of surface water, terrestrial water storage, ground water and soil moisture

Temporal variation of SW,SM,TWS and GWS was shown in Figure 2a. Fndings identifies high TWS levels in 2014 and peak surface water anomalies in 2015 due to high precipitation, low percolation, and reduced evapotranspiration. Conversely, low TWS levels in 2008 are attributed to low precipitation, high evapotranspiration, and anthropogenic activities, which can lead to drought and insufficient water supply. These findings align with broader hydrological studies that emphasize the importance of precipitation and evapotranspiration as key drivers of TWS variability. For instance, GRACE data has shown that TWS changes are closely tied to precipitation patterns and human activities, which significantly affect water availability at local and regional scales (Fokeng et al., 2024).

However, the study's findings diverge from observations in Lake Chad Basin, where surface water levels were reportedly high in 2005 and low in 2013. This discrepancy can be explained by Lake Chad's multi-catchment system, which integrates inputs from various sources such as the Chari-Logone and Komadougou Yobe rivers. In contrast, River MallamSule is a single catchment system that responds more directly to localized conditions. Studies on Lake Chad have noted significant fluctuations in surface water extent due to seasonal rainfall variations and anthropogenic factors, with a shift from a declining trend (2003–2012) to an increasing trend (2013–2022) (Ikebude & Uba, 2024). These dynamics highlight the spatial variability within interconnected hydrological systems.

Furthermore, anthropogenic activities play a significant role in shaping water quality and availability. Research on the New Calabar River in Nigeria's Niger Delta region has demonstrated how industrial discharges, urbanization, and agricultural practices degrade water quality(Ikebude & Uba, 2024). Similarly, human interventions such as irrigation and damming are noted as contributing factors to the low TWS levels observed in River MallamSule Catchment during drought years (Babati et al., 2021).

The transmission of the catchment was shown in figure 3C, the findings indicates that the water is moving toward the central part of the study area and redirected towards northeast, the findings is in line with that of which says the river of the study area is flow from the southwest-northeast direction.

RESULTS AND DISCUSSION

Trend analysis surface water, soil moisture, terrestrial water storage and groundwater

Trend Analysis of surface water, soil moisture, terrestrial water storage and groundwater anomalies was shown in Table 2. The trend analysis of hydrological components in the study area reveals a positive trend for surface water and terrestrial water storage (TWS), indicating an increase with a tendency to continue rising in the near future. This finding aligns with the research by (Gao et al., 2024), who observed similar increases in surface and TWS due to wetter conditions and reduced irrigation in the area. Such patterns are also noted in Chinese inland basins, where increased precipitation and glacier melt have offset TWS losses in some regions. However, this contrasts with global studies showing TWS declines post-2014 due to El Niño-induced droughts, highlighting regional variability where localized precipitation surges can override broader climatic trends.

In contrast, the study reports a negative trend for soil moisture and groundwater, indicating a decrease with a tendency to continue declining. This aligns with findings from semi-arid regions like China's Horqin Sandy Land, where deeper groundwater reduces soil moisture and nutrient availability (Liu et al., 2023). Similarly, mid-latitude aquifers show groundwater depletion linked to climate-driven evapotranspiration increases and anthropogenic pumping. The decline in groundwater is attributed to irrigation, consistent with global analyses linking irrigation to TWS losses. However, regions practicing managed aquifer recharge (e.g., Arizona, California) demonstrate that strategic surface water storage can mitigate groundwater depletion.

Land use Land Cover characteristic of the catchment

The land use land cover of the study area was shown in figure 3A, which comprises of rock, built up area, barren, sparse vegetation, dense vegetation, and water. The area is majorly dominated by sparse vegetation, followed by buildup area and rocks while water is the least spatial distribution in the study area, sparse vegetation has the height area, of about 170 square KM, built-up area with the total area covered of about 80 square KM, rocks has a total area of about 70 square KM, bare land has a total area of about 30 square KM, dense vegetation has a total area of about 10 square KM and water has the lowest area covered with less than 5 square KM.

Boundary definition and transmissivity within the catchment area

The boundary definition of the catchment for groundwater simulation was shown in figure 3B, the boundary consists of active cell, and inactive cell. The active cell is the cell within the catchment while the inactive cell is the cell outside the catchment. Active cells define the area where the groundwater simulation took place while inactive cell is the boundary that prevent groundwater from the boundary. The findings is in line with the work of which shows Active and inactive cell in their work.

Comparison of calibrated and uncalibrated ground water stimulated from SWAT

The calibration variation between the calibrated and uncalibrated data, shown in figure 2B the uncalibrated was overestimated before the calibration. After the calibration the bias of the data was reduced to the minimal level. The findings has so much similarity with that of, this may be as a result of closeness of both study areas. The variation between the Grace data and the simulated data, there is a very close relation between the Grace data and the simulated groundwater in 2002,2003,2005,2007,2009,2010,2011,2014,2016 and 2017 while there is variation in 2004,2006,2008,2012,2013 and 2015 (figure 2C). The simulation of groundwater across the catchment. The Eastern and southeastern part of the study area has the highest level of groundwater respectively which may be as a result of low extraction, the area is covered with rocks, and therefore resulted in low groundwater extraction due to the absence of settlements and human activities. Moderate value of groundwater was observed around Potiskum which may also be as a result of regular extraction because of the high demand of groundwater by individuals and low value was observed around southwest of the study area which may also be as a result of the sparse vegetation cover and few overlaying settlements located across the area. This result is in line with the findings of (Babati et al., 2021), which shows the groundwater level in part of the study area.

Trend analysis of predicted groundwater

The trend analysis of projected groundwater from 2020 -2029, 2030 -2039, 2040 -2049 and 2020 -2050 was shown in table 4. The trend analysis of projected groundwater of 2020 -2029, 2030 -2039, 2040 -2049 has a negative trend which indicate a decrease trend with the tendency of groundwater decrease in the nearest future. This result is in line with the findings of, which established a decline in the groundwater level from 1990-2010.

The trend analysis from 2020 -2050 of groundwater shows a positive trend which indicate an increase trend with a tendency of increasing in the nearest future. Although despite the trend observed no period shows a significant trend since the p-value is more than the Alpha. Table 5 shows the mean value for 2020 -2029 predicated groundwater level is 18.03, 2030 -2039 is 19.17, 2040 - 2049 is 20.91 and 2049 -2050 is 15.13 respectively. The standard deviation for 2020 -2029 is 8.51, 8.87, 9.18, 3.73 for 2030 -2039, 2040 -2049, 2020 -2050 respectively. Finally, the coefficient variation for 2020-2029 is 0.46, 0.45, 0.43 and 0.24 for 2030 -2039, 2040 -2049 and 2020 -2050 respectively.

The observed negative trend in groundwater levels from 2020–2029, 2030–2039, and 2040–2049 correlates with findings that highlight groundwater depletion due to anthropogenic activities such as over-extraction and poor management practices. For example, studies in Irun Akoko, Ondo State, reveal seasonal variability in groundwater availability, with shallow wells drying up completely during the dry season due to insufficient recharge and increased demand (Adebayo et al., 2021). Similarly, research on water quality monitoring in Nigeria underscores the growing reliance on groundwater for domestic use, driven by perceptions of its purity and accessibility, despite its vulnerability to contamination and depletion (Ewuzie et al., 2021).

The positive trend projected for groundwater levels from 2020–2050 contrasts with these findings but may reflect localized improvements due to changes in abstraction rates or improved water management strategies. However, studies suggest that such improvements are rare without significant policy interventions or infrastructure development. For instance, the review of water infrastructure development in Nigeria highlights the need for sustainable practices to mitigate groundwater depletion and enhance recharge(Adeniran et al., 2021). Additionally, the statistical insignificance of observed trends aligns with broader studies that emphasize variability in groundwater dynamics due to climatic and geological factors. Southwestern Nigeria, which has abundant rainfall and diverse aquifer systems, demonstrates significant spatial variability in groundwater quality and availability. This variability complicates efforts to establish clear trends without long-term data collection and analysis(Omeka et al., 2024).

Spatial distribution of the groundwater water

The spatial distribution of the groundwater water in the catchment from 2020 -2029 was shown in figure 4A, the southwestern part of the study area has the lowest level of groundwater (12 -25) and a coherence distribution of the groundwater from northwest to southeast. Moderate value of groundwater (38-49) was observed around the North central part down to the south central part of the map. Potiskum area has a low value in the western part of the town (26-37), and moderate across the core central part of the town (38-49). High value of groundwater was observed in the far eastern part of the study area (50-61), the highest value was observed around the eastern area down to the southeastern part of the study area (62-74). This may be as a result of low extraction due to the nature of the land which is covered by basement complex rock. This findings disagrees with that of Edmunds et al., (2012) which may possibly be as a result of variation of the period of interest..

The spatial distribution of groundwater in River MallamSule catchment, Yobe State from 2030 -2039 was shown in figure 4B, western part of the study area has the lowest ground water level (12-25), this may be as a result of high intake from the vegetation which covered most part of the area. Northern part of the study area and its coherence has high value of groundwater (21 - 25). The eastern and Southeastern part of the study area and its coherence has the highest value of groundwater respectively (62 - 74), this may be as a result of the overlaying rock present in the area. This finding disagrees with that of as a result of variation of period of interest.

The spatial distribution of groundwater in River MallamSule catchment, Yobe State from 2040- 2049 was shown in figure 4C the western overlaying area and its coherence in the study area has the lowest level of groundwater (12 -25), the northern part of the study area and its coherence has a low to very low groundwater water value (12-25, 26-37). Potiskum area and its coherence has a medium level of groundwater (38-49) the groundwater in the southeastern part of the study area decreases drastically from very high to high, with a respective value of (62-74 to 50-61). The findings disagree with that as a result of variation of period of interest.

These findings show variations in groundwater levels across different regions, influenced by factors such as land use, rock formations, and extraction rates. For instance, the southwestern part of the study area has the lowest groundwater levels, while the eastern and southeastern parts have the highest levels, attributed to factors like low extraction due to basement complex rock and overlaying rock formations, respectively. When compared to other studies, such as Edmunds et al., (2012), the findings from your study disagree primarily due to differences in the period of interest. This suggests that temporal variations and changes in environmental conditions over time can significantly impact groundwater levels and distribution. Similarly, the study in River Mallam Sule catchment, Yobe State, also shows disagreements with other studies due to variations in the period of interest. This indicates that groundwater dynamics can change significantly over time, influenced by factors like land use changes, extraction rates, and geological conditions.

Other studies, such as those focusing on groundwater surveillance in Nigeria, have identified declining groundwater levels attributed to factors like uncontrolled groundwater discharge and urbanization. While not directly comparable in terms of spatial distribution, these studies support the idea that groundwater levels are influenced by human activities and environmental changes. Additionally, simulations using models like SWAT have found high, moderate, and low levels of groundwater in similar areas, indicating groundwater stress. This aligns with your findings of varying groundwater levels across different parts of the study area.

Overall, while there are disagreements due to temporal variations, all studies emphasize the impact of environmental and human factors on groundwater levels. This underscores the need for continuous monitoring and consideration of temporal changes when analyzing groundwater distribution. The agreement lies in recognizing the role of land use, rock formations, and extraction rates in shaping groundwater dynamics, while disagreements stem from the challenges of comparing findings across different time frames.

Table 1: Variability of surface water, soil moisture, terrestrial water and groundwater anomalies**.**

Statistic	ΔSW	ΔSM	ΔTWS	ΔGW
Mean	50.6189	59.7324	33.8934	49.8821
Variance	891.2612	639.4970	964.1212	976.6212
Standard deviation	29.8540	25.2883	31.0503	31.2509
coefficient Variation	0.5711	0.4099	0.8870	0.6066

Table 2: Trend analysis of surface water, soil moisture, terrestrial water storage and groundwater anomalies.

	ΔSW	ΔSM	ΔTWS	ΔGWS
Kendall's tau	0.1667	-0.0500	0.6333	-0.0333
S	20.0000	-6.0000	76.0000	-4.0000
p-value	0.3984	0.8248	0.0003	0.8944
Alpha	0.05	0.05	0.05	0.05

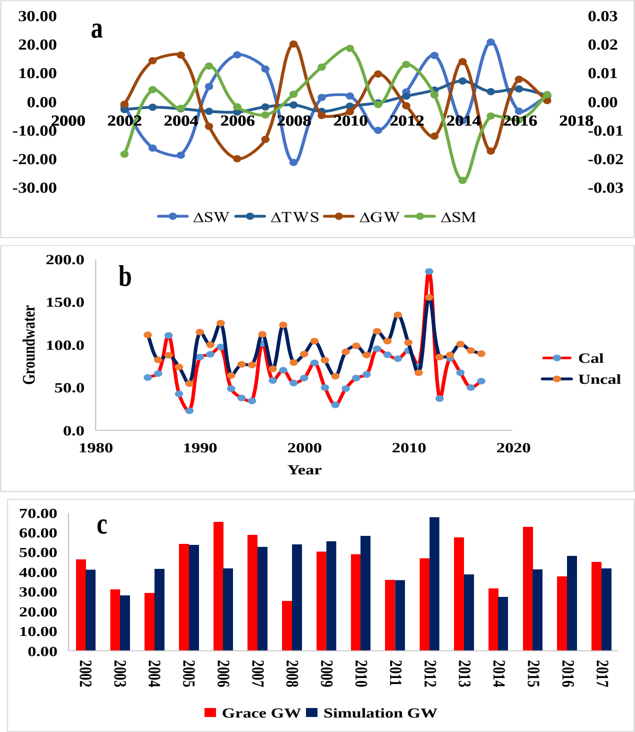

Figure 2: (a) Anomalies of surface water, terrestrial water storage, ground water and soil moisture (b) Comparison of calibrated and uncalibrated ground water stimulated from SWAT (C) Variation of groundwater stimulation using GRACE and SWAT

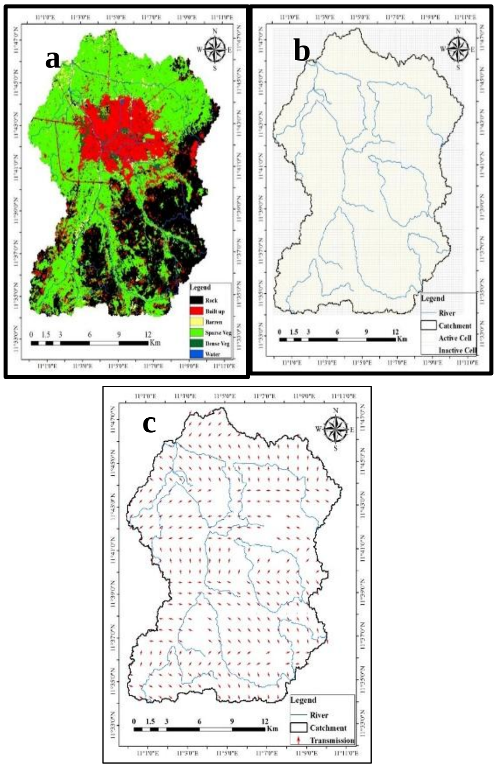

Figure 3: (a)LULC, (b) CELL and (C): Transmission

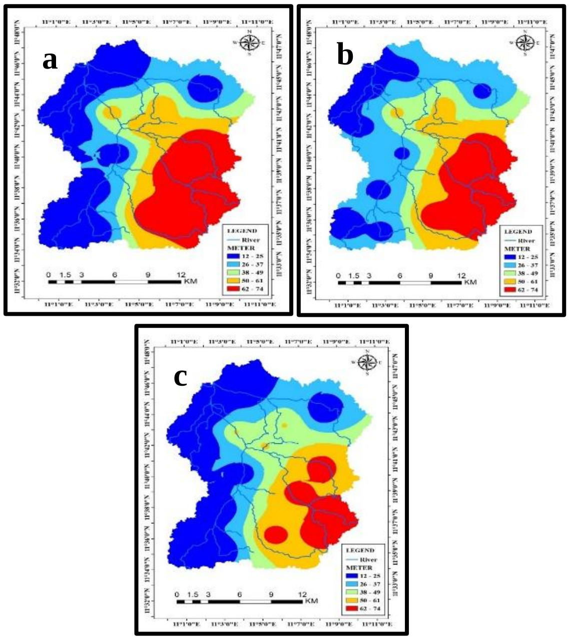

Figure 4: Spatial Distribution of Groundwater in the Study Area (a) 2020-2039, (b) 2030-2039, (c) 2040-2049

Table 3: Trend Analysis of Projected Groundwater

	2020-2029	2030-2039	2040-2049	2020-2050
Z	-0.25	-0.19	-0.25	0.12
S	-43.00	-33.00	-43.00	57.00
p-value	0.14	0.27	0.14	0.34
Alpha	0.05	0.05	0.05	0.05

Source: Author's Analysis, 2020

Table 4: Variability Analysis of Projected Groundwater

Statistic	2020-2029	2030-2039	2040-2049	2020-2050
Mean	18.03	19.17	20.91	15.13
STD	8.51	8.87	9.18	3.73
CV	0.46	0.45	0.43	0.24

Source: Author's Analysis, 2020

Conclusion

The result concludes that, surface water and terrestrial water storage shows increase in trend, while soil moisture and groundwater shows decrease in trend. The trend analysis of projected groundwater revels that 2020 -2029, 2030 -2039, 2040-2049 shows decrease in trend, while from 2020 -2050 shows increase in trend. The spatial distribution of groundwater in the catchment from 2020 -2029 revealed that the northwestern and southwestern part of the study area has the lowest level of groundwater, Potiskum area has a moderate value and a very low value was observed in the southwest of the study area. South of Potiskum shows low level as well. From the year 2030-2039 western part of the study area has a very low level. The northern part and its environs have low value of groundwater, Potiskum area and its environs has a medium level of groundwater, the southeastern part of the study area has very high level of groundwater. From 2040-2050 the northwestern part of the study area has very low level, whereas the northeastern part of the study area has high level, Potiskum area has a medium level of groundwater, and the southwestern part of the study area shows significant decrease in ground water value from very high to high.

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