The Future We Want – The SDGs and Beyond: Land Governance, Geospatial Intelligence, and Technological Pathways for Climate Resilience and Equitable Growth

Onyeizu Chukwuemeka Enyinnaya, Nigeria

Key words: Sustainable Development Goals, Land Governance, Geospatial Intelligence, Terrestrial Water Storage, GRACE, Climate Resilience, Equitable Growth

1. SUMMARY

Nigeria faces significant challenges in achieving Sustainable Development Goal 6 (Clean Water and Sanitation) due to climate variability, land degradation, and weak governance. Uneven freshwater distribution, shrinking Lake Chad, floods, and droughts underscore the fragility of current systems. The paper emphasizes the role of geospatial intelligence particularly satellite missions like GRACE and GRACE-FO in monitoring Terrestrial Water Storage (TWS) and informing climate resilience strategies. Findings reveal that precipitation and evapotranspiration are primary drivers of TWS variability, with strong north-south contrasts across river basins. Southern basins recover better during wet seasons, while northern basins suffer persistent deficits, highlighting the need for basin-specific governance rather than uniform national policies. Groundwater emerges as a critical buffer against climate stress, but unregulated abstraction threatens sustainability. Integrating GRACE-based data with hydrological models, machine learning, and GIS platforms enables early warning systems, drought forecasting, and evidence-based land governance. These technologies support equitable growth, agricultural productivity, and policy coherence. The study advocates for embedding geospatial intelligence into national frameworks, strengthening River Basin Development Authorities, and promoting transparent governance. Ultimately, convergence of technology, governance, and equity is essential for building a climate-resilient and inclusive future beyond 2030, transforming vulnerability into opportunity.

SUMMARY (Igbo language)

Naịjirịa na-eche nnukwu ihe ịma aka n’ịrụpụta Ebumnuche Mmepe Nkwụsi nke 6 (Mmiri Dị Ọcha na Ịsa Ahụ) n’ihi mgbanwe ihu igwe, mmebi ala, na ọchịchị na-adịghị ike. Nkesa mmiri dị ọcha na-adịghị kwekọrọ, mkpụmkpụ ọdọ mmiri Chad, ide mmiri, na ajọ mmiri na-egosi adịghị ike nke usoro dị ugbu a. Akwụkwọ a na-ekwusi ike mkpa ọgụgụ isi geospatial—karịsịa ọrụ satịlaịtị dịka GRACE na GRACE-FO-n’ịnyocha Mmiri dị n’ala (TWS) ma na-enye ndụmọdụ maka atụmatụ ịdịgide ihu igwe. Nchọpụta gosiri na mmiri ozuzo na evapotranspiration bụ ihe ndị bụ isi na-akpata mgbanwe TWS, yana nnukwu ọdịiche n’ebe ugwu na ebe ndịda n’ime ọdọ mmiri Naịjirịa. Odọ mmiri ndịda na-enweta mgbake ka mma

n’oge mmiri, ebe ọdọ mmiri ugwu na-enwe nsogbu mgbe niile, nke na-egosi mkpa ọchịchị pụrụ iche maka ọdọ mmiri kama iwu mba zuru oke.

Mmiri dị n’ala (groundwater) pụtara dị ka ihe nchekwa dị mkpa megide nrụgide ihu igwe, mana ịkpọpụghị ya n’usoro nwere ike imebi ịdịgide ya. Ịjikọta data GRACE na nlereanya mmiri, machine learning, na GIS na-enyere aka n’ịmepụta usoro ịdọ aka ná ntị tupu ide mmiri, amụma ajọ mmiri, na ọchịchị ala dabere na ihe akaebe. Teknụzụ ndị a na-akwado uto kwekọrọ, mmepụta ugbo, na nkwụsi ike iwu. Omụmụ a na-akwado itinye ọgụgụ isi geospatial n’ime usoro mba, ime ka River Basin Development Authorities sie ike, na ịkwalite ọchịchị doro anya. N’ikpeazụ, ijikọ teknụzụ, ọchịchị, na nhata bụ isi ihe dị mkpa iji wulite ọdịnihu siri ike ma kwekọrọ gafee 2030, na-agbanwe adịghị ike ka ọ bụrụ ohere.

The Future We Want – The SDGs and Beyond:

Land Governance, Geospatial Intelligence, and Technological Pathways for Climate Resilience and Equitable Growth

Onyeizu Chukwuemeka Enyinnaya, Nigeria

Introduction

Sustainable development requires balancing economic growth, environmental protection, and social equity. In Nigeria, climate variability, land degradation, and water crises hinder progress toward the SDGs. Uneven distribution of freshwater resources, shrinking of Lake Chad, recurrent floods, and prolonged droughts highlight the fragility of existing systems. These challenges are compounded by weak land governance, rapid urbanization, and inadequate hydrological monitoring.

Technological innovations, particularly in geospatial intelligence, offer new pathways for resilience. Missions such as GRACE and GRACE-FO revolutionize monitoring of TWS, providing data on groundwater, soil moisture, and surface water dynamics. When integrated with climate forecasting, land governance, and socio-economic policies, these insights can shape equitable and sustainable futures beyond 2030.

The global commitment to The Future We Want articulated through the 2030 Agenda for Sustainable Development recognizes land and water as foundational assets for human well-being, economic development, and ecological sustainability (United Nations, 2015). Yet, climate change, population growth, and weak land governance structures continue to undermine equitable access to these resources, particularly in developing countries. Nigeria exemplifies this challenge, where spatial disparities in water availability, land degradation, and rapid urban expansion intersect with climate variability.

Geospatial intelligence, enabled by satellite remote sensing and advanced spatial analytics, has emerged as a transformative tool for understanding and managing land water systems. Satellite gravimetry missions such as the Gravity Recovery and Climate Experiment (GRACE) and GRACE Follow-On (GRACE-FO) now allow for the monitoring of Terrestrial Water Storage (TWS) at regional to continental scales. These innovations provide a unique opportunity to bridge scientific evidence with land governance reforms and SDG implementation.

This paper builds on the author's MSc research on TWS dynamics across Nigeria's river basins, narrowing its focus to Objectives 3 and 4. By reframing these objectives within the SDG and land governance discourse, the paper demonstrates how geospatial intelligence can inform climate resilience strategies and support equitable growth pathways.

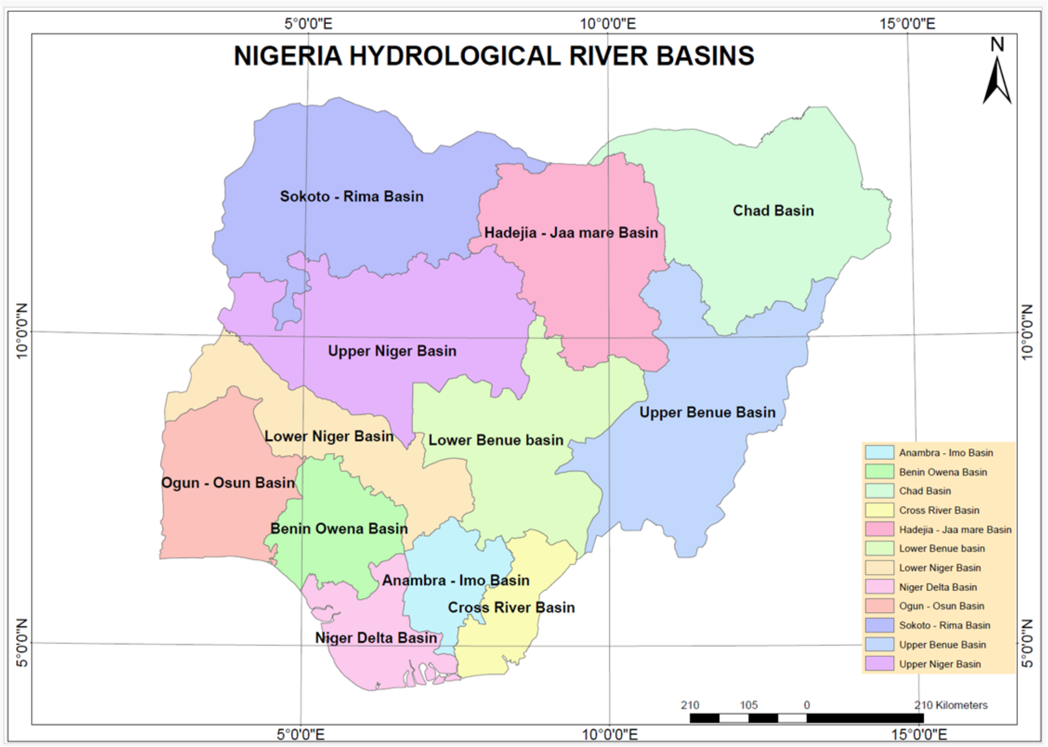


Figure 1: River Basin Development Authorities in Nigeria

Land Governance and Sustainability Beyond 2030

Land governance underpins sustainable water and resource management. Weak governance structures, poor enforcement of regulations, and uncoordinated urban expansion worsen Nigeria's vulnerability to floods, droughts, and water scarcity. Key reforms include:

1. Strengthening River Basin Development Authorities (RBDAs) with basin-specific strategies for drought-prone northern regions and flood-prone southern basins.
2. Promoting equitable land use through agroforestry, reforestation, and soil conservation to reduce evapotranspiration losses.
3. Enhancing institutional transparency to ensure equitable access to water resources, directly linking governance to SDG 6 targets.

Geospatial Intelligence and Climate Resilience

The integration of geospatial technologies into hydrological monitoring enables real-time decision-making. GRACE/GRACE-FO missions provide high-resolution gravitational anomaly data, tracking water redistribution at national and basin scales. Applications include:

- ✓ Flood early warning systems: Monitoring TWS fluctuations to anticipate flood risks in coastal and riverine regions.
- ✓ Drought preparedness: Coupling GRACE with the Standardized Precipitation Index (SPI) and machine learning for drought onset forecasting.
- ✓ Groundwater sustainability: Detecting aquifer depletion in northern Nigeria, supporting adaptive recharge policies.

These advances show that geospatial intelligence bridges scientific knowledge and actionable governance, enabling resilience under accelerating climate uncertainty.

Conceptual Framework: SDGs, Land Governance, and Geospatial Intelligence

Land governance refers to the rules, institutions, and processes that determine how land and related resources are accessed, used, and managed (FAO, 2012). Effective land governance is central to achieving SDGs related to poverty reduction (SDG 1), food security (SDG 2), water management (SDG 6), sustainable cities (SDG 11), climate action (SDG 13), and ecosystem protection (SDG 15).

Geospatial intelligence strengthens land governance by providing spatially explicit evidence on environmental change. In the context of water resources, satellite-derived indicators such as precipitation, evapotranspiration, groundwater storage, and TWS anomalies enable decision-makers to visualize risks, prioritize interventions, and monitor outcomes. When integrated into policy frameworks, these tools support transparent, inclusive, and adaptive governance systems.

Within this framework, Objectives 3 and 4 of the underlying research align directly with SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), while also contributing indirectly to SDGs 8, 11, and 15 by informing sustainable land-use planning and resilience building.

Influence of Precipitation and Evapotranspiration on Terrestrial Water Storage

Hydro-Climatic Controls on TWS

Precipitation and evapotranspiration are primary drivers of terrestrial water balance. Precipitation represents the main input to land-based water systems, while evapotranspiration constitutes a major loss pathway linking land surface processes with atmospheric dynamics (Rodell et al., 2018). Variations in these variables therefore exert direct control on observed TWS anomalies.

Using GRACE/GRACE-FO-derived TWS data in conjunction with precipitation and evapotranspiration datasets, the study reveals pronounced seasonal and interannual variability across Nigeria’s river basins. Wet-season months (April–October) are associated with positive TWS data variations, reflecting increased surface water and soil moisture recharge. Conversely, dry-season periods (November–March) show widespread negative anomalies driven by reduced rainfall and heightened evapotranspiration.

Spatial Differentiation Across River Basins

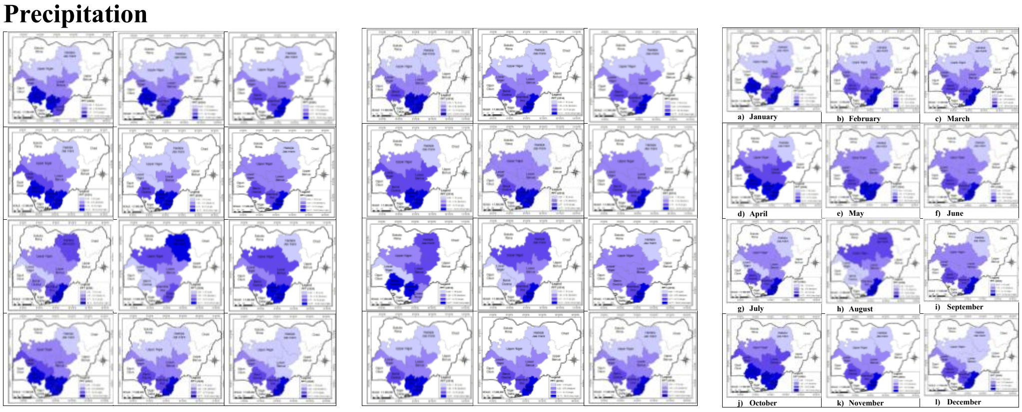
The analysis demonstrates strong north - south contrasts in hydro-climatic influence. Southern basins such as the Lower Benue and Cross River exhibit higher sensitivity to precipitation inputs, resulting in stronger TWS recovery during wet seasons. In contrast, northern basins including Sokoto–Rima and Chad Basin experience persistent deficits due to low rainfall and high evapotranspiration rates.

These spatial patterns underscore the importance of basin-specific land and water governance strategies. Uniform national policies may fail to capture localized vulnerabilities, whereas geospatial intelligence enables targeted, evidence-based interventions aligned with SDG 6 targets on integrated water resource management.

Evapotranspiration

2024 **2014** **2004**

Precipitation



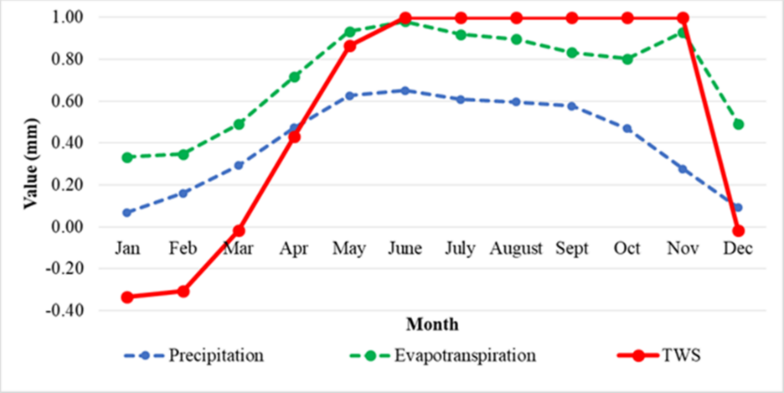
2024 **2014** **2004**

Figure 2: Precipitation and Evapotranspiration along the RBDA for 2024, 2014 1and 2004

Interpretation of Results: Influence of Precipitation and Evapotranspiration on Observed TWS Variations.

Month	Precipitation	Evapotranspiration	TWS
Jan	7.5809	29.2838	-73.98
Feb	16.0536	18.8160	-65.48
Mar	52.8517	36.0096	-92.12
Apr	111.8013	57.4560	-67.11
May	176.2896	86.3040	-18.97
June	198.4695	100.0800	6.02
July	226.6488	115.7664	29.90
August	249.2133	125.1408	43.34
Sept	281.0452	124.4160	81.27
Oct	157.9509	112.3440	66.59
Nov	36.6085	86.2272	9.38
Dec	10.4484	46.2768	-58.70

Precipitation exhibits pronounced seasonal variability, increasing from 7.58 mm in January to a peak of 281.05 mm in September before declining sharply toward the dry-season minimum in December, a pattern characteristic of Nigeria's monsoonal climate. This seasonal rainfall regime exerts a strong influence on southern river basins, such as the Cross River and Lower Benue, where higher wet-season precipitation contributes to enhanced terrestrial water storage. Evapotranspiration increases steadily from 29.28 mm in January to a maximum of 125.14 mm in August, reflecting elevated temperatures, vegetation growth, and soil moisture availability during the wet season, before decreasing as moisture conditions diminish. Correspondingly, terrestrial water storage anomalies transition from pronounced deficits during the dry season to positive values during the rainy months, peaking in September (81.27) and subsequently declining toward negative anomalies by December as rainfall and evapotranspiration decrease. This Figure below, illustrates the spatial variability of evapotranspiration across different basins in 2024. It highlights the regional differences in evapotranspiration, with the southern basins (like Cross River and Lower Benue) experiencing higher evapotranspiration due to more significant rainfall and vegetation cover. In contrast, northern regions (such as Sokoto-Rima and Hadejia-Jaa Mare) show lower evapotranspiration, which aligns with lower rainfall and more arid conditions. The figure visually reinforces the observation that evapotranspiration is highly linked to local rainfall patterns, with southern basins exhibiting stronger evapotranspiration due to higher precipitation



Implications for Climate Resilience

Declining wet-season TWS recovery observed in recent years suggests increasing climate stress, consistent with broader trends of rising temperatures and evapotranspiration. This has implications for agricultural productivity, ecosystem services, and rural livelihoods. From an SDG perspective, the findings reinforce the need to integrate climate data into land-use planning and water allocation frameworks to enhance adaptive capacity.

Groundwater Storage Anomalies and Interactions with Hydrological Components

Groundwater as a Climate Buffer

Groundwater constitutes a critical component of TWS, often serving as a buffer during periods of surface water scarcity. By isolating groundwater storage anomalies through the integration of GRACE-derived TWS with soil moisture and surface water datasets, the study reveals that groundwater exhibits comparatively stable trends across most basins.

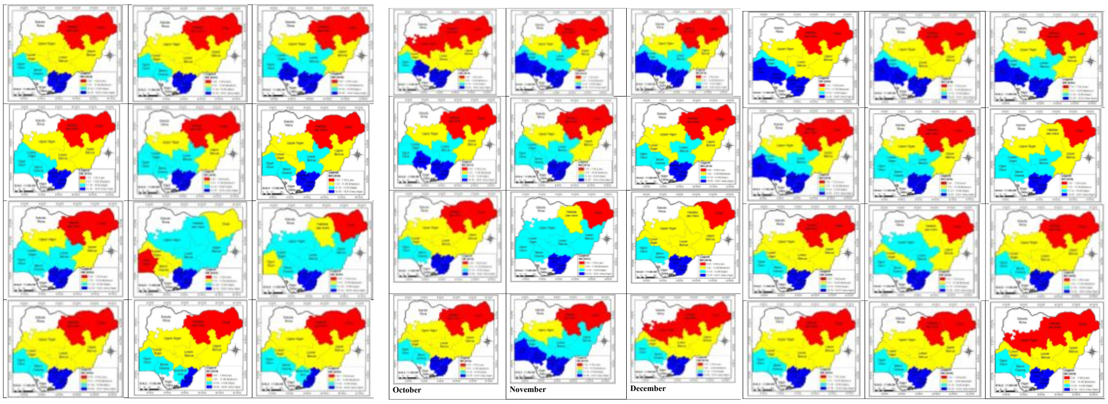
This stability highlights groundwater's strategic importance for climate resilience, particularly in semi-arid and drought-prone regions. However, it also raises governance concerns, as unregulated abstraction can undermine long-term sustainability.

Interaction with Surface Water and Soil Moisture

The results indicate that surface water and soil moisture respond more rapidly to precipitation variability, while groundwater responds more slowly but sustains baseflow during dry periods. In southern basins, strong coupling between surface water and groundwater enhances overall system resilience. In contrast, weaker coupling in northern basins increases vulnerability to prolonged droughts.

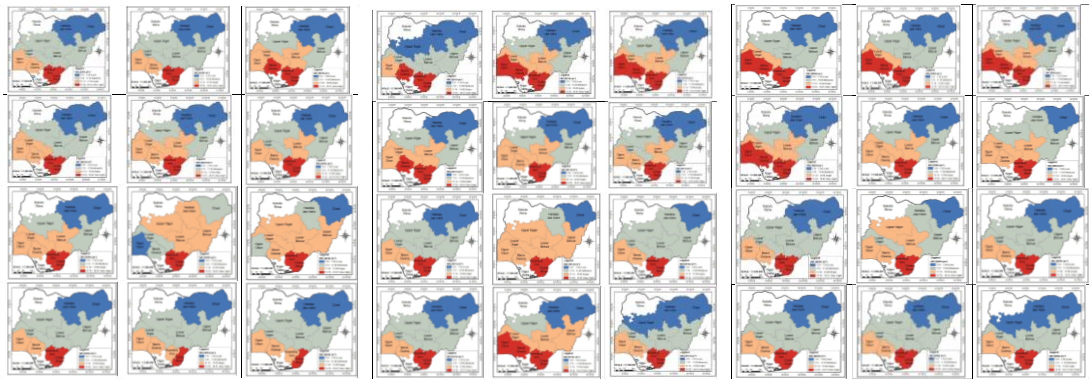
These interactions emphasize the need for integrated land–water governance that accounts for subsurface resources, which are often overlooked in conventional planning. Incorporating groundwater intelligence into national geospatial data infrastructures can improve transparency and accountability in resource allocation.

Soil Moisture



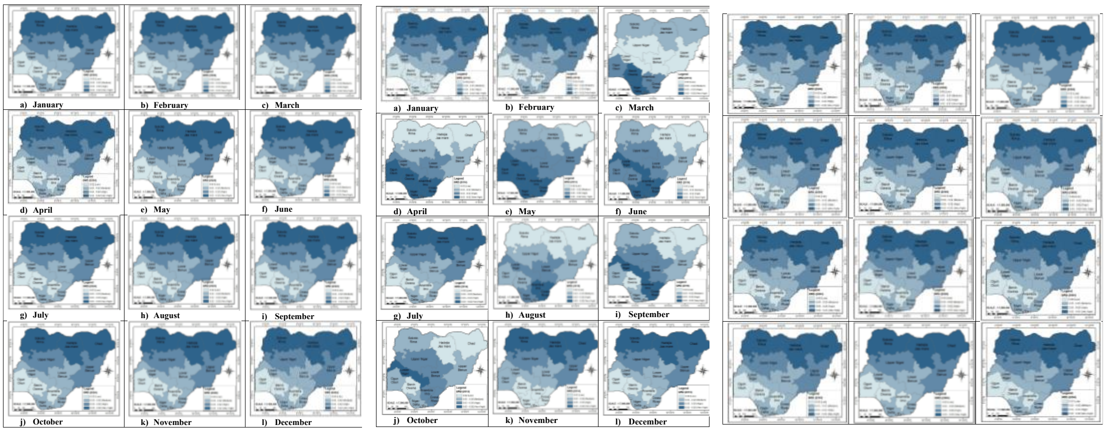
2024 **2014** **2004**

Surface Water



2024 **2014** **2004**

Groundwater



2024 **2014** **2004**

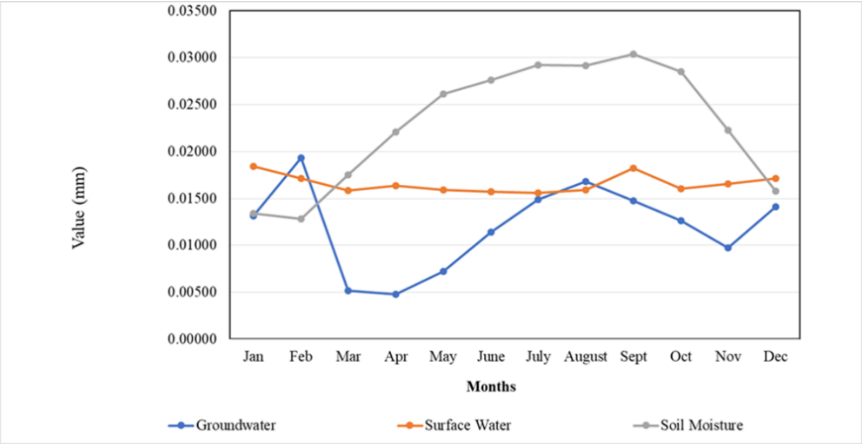
Figure 3: Soil Moisture, Surface water and Groundwater along the RBDAs for 2024, 2014 1and 2004

Interpretation of Results: Variation of Groundwater with Other Hydrological Components

The table below shows that, in 2004, groundwater storage exhibits clear seasonal variability, increasing from January (0.01312) to a peak in August (0.01678) in response to wet-season recharge, before declining in September and remaining relatively stable through the dry months. This pattern indicates strong climatic control on groundwater dynamics, with recharge during periods of high precipitation and gradual depletion as rainfall diminishes, a trend clearly illustrated in Figure 4.5. Surface water storage follows a comparable seasonal trajectory, rising through the rainy season to a maximum in September (0.01820) before decreasing toward December, reflecting the rainfall-driven nature of river discharge and runoff processes.

Month	Groundwater	Surface Water	Soil Moisture
Jan	0.01312	0.01841	0.01341
Feb	0.01930	0.01716	0.01285
Mar	0.00520	0.01585	0.01751
Apr	0.00479	0.01635	0.02209
May	0.00725	0.01592	0.02612
June	0.01143	0.01573	0.02758
July	0.01489	0.01558	0.02924
August	0.01678	0.01588	0.02915
Sept	0.01475	0.01820	0.03040
Oct	0.01261	0.01605	0.02850
Nov	0.00974	0.01657	0.02228
Dec	0.01408	0.01715	0.01577

The figure below illustrates the seasonal response of surface water within the hydrological cycle, showing increases during periods of high rainfall and declines as precipitation diminishes. Soil moisture exhibits a more pronounced seasonal increase than groundwater and surface water, rising steadily from 0.01341 in January to a peak of 0.03040 in September, reflecting strong sensitivity to wet-season precipitation and soil water retention processes. Following the rainy season, soil moisture remains relatively elevated but declines toward December (0.01577) due to reduced rainfall and increased evaporative losses, a trend that closely mirrors the seasonal rainfall pattern.



Equity and Sustainable Growth Dimensions

Equitable growth depends on reliable access to water for agriculture, industry, and domestic use. Groundwater depletion disproportionately affects rural communities and smallholder farmers, exacerbating inequality. By providing basin-scale evidence of groundwater dynamics, geospatial intelligence supports inclusive decision-making and aligns with the SDG principle of "leaving no one behind."

Technological Pathways for SDG Implementation

The integration of GRACE/GRACE-FO data, GIS platforms, and spatial analytics represents a technological pathway for operationalizing the SDGs. These tools enable:

- **Evidence-based land governance**, through spatial monitoring of water–land interactions.
- **Early warning systems** for droughts and floods, enhancing disaster risk reduction.
- **Policy coherence**, by linking environmental indicators with development planning.
- **Capacity building**, particularly in data-scarce regions where ground monitoring is limited.

Embedding such technologies within institutional frameworks can accelerate progress toward climate-resilient and equitable development.

Technological Advancements and Equitable Growth

Beyond geospatial monitoring, innovations in machine learning, hydrological modeling, and data assimilation enhance forecasting accuracy. For example, hybrid models combining GRACE data with precipitation and evapotranspiration datasets improve localized water accounting in data-scarce regions.

Such technologies support:

1. Equitable growth: By improving water access across rural and urban areas, reducing conflict over scarce resources.
2. Agricultural productivity: Enhancing irrigation efficiency and ensuring food security amid climate stress.
3. Policy innovation: Providing evidence-based tools for SDG dashboards and climate adaptation strategies.

The Future We Want: Pathways Beyond 2030

Achieving sustainability beyond 2030 requires convergence of governance, technology, and equity. This paper proposes three key pathways:

1. Integrated Water and Land Governance – Establishing frameworks that unite land use, water allocation, and climate resilience under transparent policies.
2. Technology-Enabled Monitoring and Forecasting – Scaling satellite-based geospatial intelligence, AI, and IoT-enabled sensors for inclusive decision-making.
3. Equitable Growth and Resilience – Embedding climate justice in development planning, ensuring vulnerable communities' benefit from innovations and governance reforms.

Conclusion and Policy Implications

This study demonstrates that geospatial intelligence constitutes a vital interface between land governance, climate resilience, and the realization of the Sustainable Development Goals (SDGs). By examining the influence of precipitation and evapotranspiration on Terrestrial Water Storage and assessing groundwater storage anomalies in relation to other hydrological components, the paper illustrates how satellite-derived evidence can inform sustainable and equitable development strategies in data-constrained contexts such as Nigeria.

The results reveal pronounced spatial heterogeneity in hydro-climatic controls across Nigeria's river basins, underscoring the limitations of uniform national water management policies. Instead, the findings support the adoption of basin-specific land and water governance approaches that reflect localized climatic and hydrological conditions. Groundwater is identified as a critical resilience resource, providing buffering capacity against climatic variability, yet its long-term sustainability depends on strengthened regulatory frameworks to prevent over-extraction. Collectively, these insights advance progress toward SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), while also contributing to SDGs 11 and 15 through enhanced land-use planning and ecosystem conservation.

From a policy standpoint, the study highlights the imperative to mainstream geospatial intelligence within national land and water governance systems. The systematic integration of GRACE-based hydrological indicators into River Basin Development Authority (RBDA) planning processes, national SDG monitoring mechanisms, and climate adaptation frameworks would significantly improve evidence-based decision-making, institutional transparency, and distributive equity. Achieving this integration will require sustained investments in technical capacity development, open geospatial data infrastructures, and coordinated cross-sectoral collaboration.

Ultimately, realizing *The Future We Want* depends on the capacity of governments and institutions to strategically harness advanced geospatial technologies in support of inclusive and climate-resilient growth. This paper affirms that satellite-derived hydrological intelligence extends beyond scientific innovation to function as a governance instrument capable of accelerating SDG implementation and safeguarding land and water resources for future generations. While Nigeria's land and water challenges reflect broader global sustainability pressures, the alignment of geospatial intelligence with robust governance structures and inclusive policy frameworks offers a pathway for transforming vulnerability into opportunity. Beyond the SDGs, the future envisioned is one in which technology strengthens governance, land resources are managed equitably, and resilience to climate change underpins sustainable development for all.

References

Adebayo, O., Eludoyin, A., & Fashae, O. (2021). Climate variability and water availability in Nigeria: Implications for sustainable development. International Journal of Climatology, 41(5), 2345–2360. https://doi.org/10.1002/joc.6789

Adetokunbo, P., Eluyemi, A. A., Aguda, S., Jegede, E., Omoseyin, T., Sanuade, O. A., & Adesina, R. B. (2025). Decadal trends and periodicity of terrestrial water storage in Nigeria—GRACE satellite observations. Open Journal of Geology, 15(7), 343–357. https://doi.org/10.4236/ojg.2025.157017.

Ahile, S. I., Mailumo, D. A., & Ikape, M. O. (2024). Nigeria's water crisis and the challenge of meeting the sustainable development goals. International Journal of Innovative Environmental Studies, 3(4), 55–70.

Mandal, D., Das, N., & Chanda, A. (2025). Machine-learning-based reconstruction of long-term global terrestrial water storage anomalies. Environmental Science and Data, 17, 2575–2602. https://essd.copernicus.org/articles/17/2575/2025/.

Martins, G., Ehinmentan, B., Mafimisebi, P., America, A., & Gbadero, G. (2025). Sustainable water resource management in Nigeria: Challenges, integrated water resource management implementation, and national development. International Journal of Trendy Scientific Research, 5(3), 45–63.

Rodell, M., Famiglietti, J. S., Wiese, D. N., Reager, J. T., Beaudoin, M., Landerer, F. W., & Lo, M. (2018). Emerging trends in global freshwater availability. Nature, 557, 651–659. https://doi.org/10.1038/s41586-018-0123-1

BIOGRAPHICAL NOTES

Onyeizu Chukwuemeka Enyinnaya is an accomplished geospatial professional, surveyor, and project manager with more than two decades of experience in GIS, hydrographic and terrestrial surveying, disaster risk management, and environmental studies. He holds a PhD in Disaster Risk Management and Development Studies and currently works as a Project Surveyor and GIS Expert, supporting major infrastructure, environmental, and land administration projects in Nigeria. His work focuses on integrating geospatial intelligence into planning, resilience building, environmental protection, and sustainable community development.

CONTACTS

Surv. Chukwuemeka Enyinnaya ONYEIZU (PhD)
MalionGeodata Nigeria Limited
No 5 Vongo Crescent, Off Ahiaba Umueze Road,
Aba, Nigeria
Tel. +348035702822, +2349027410429
Email: maliongeodatanigerialimited@gmail.com
Web site: