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Hydrometeorological Monitoring Infrastructure in Nigeria's Hadejia River Basin: Functionality, Network Adequacy, and Institutional Constraints

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Abstract

Hydrometeorological monitoring networks provide critical data for water resources management, flood forecasting, and climate risk assessment. However, many river basins in developing regions experience declining monitoring capacity due to institutional and technical constraints. This study evaluates the hydrometeorological monitoring infrastructure within the jurisdiction of the Hadejia-Jama'are River Basin Development Authority (HJRBDA) in northwestern Nigeria. Field inspections and key informant interviews conducted in 2024 documented station infrastructure, assessed equipment functionality, and examined recent modernization interventions. Results reveal uneven operational performance. Stations at Tiga Dam and HJRBDA headquarters remained operational, while more than 23 telemetric installations under the TRIMING project actively transmitted real-time data. In contrast, the monitoring station at Chalawa Gorge Dam, including a NEWMAP-installed automatic weather station, was non-functional. Interviews identified inadequate maintenance capacity, absence of dedicated operational budgets, limited spare parts, and insufficient technical training as key sustainability constraints. Relative to the basin's area (approximately 43,285 km²), the current monitoring network falls below World Meteorological Organization (WMO) station density recommendations. The study highlights the need to integrate monitoring infrastructure into institutional operational frameworks to ensure sustained data availability in semi-arid river basins.

Keywords: Hydrometeorological Monitoring, River Basin Management, Monitoring Networks, Automatic Weather Stations, Institutional Capacity.

Introduction

Reliable hydrometeorological observations from in-situ networks are fundamental for water resources management, flood forecasting, and climate adaptation (WMO, 2021). Their importance has increased in sub-Saharan Africa, where hydroclimatic extremes are becoming more frequent. In Nigeria, the 2022 floods affected approximately 2.8 million people and caused an estimated US$4 billion in damages, highlighting the need for effective monitoring and early warning systems (NIHSA, 2022). Despite this, many developing countries face major deficiencies in monitoring systems, including limited spatial coverage, aging equipment, inadequate maintenance, insufficient funding, and personnel shortages (Perera et al., 2020; Isukuru et al., 2024).

The WMO recommends approximately one rainfall station per 575 km² in tropical plains (Garba & Abdourahamane, 2023). However, many regions of sub-Saharan Africa fall far below this threshold (Dinku et al., 2018). Researchers often rely on interpolation or satellite-derived rainfall products to compensate for data gaps, but these approaches have limitations: rainfall exhibits strong spatial variability, and satellite estimates require ground-based calibration (Chen et al., 2017; Maidment et al., 2017). Weak in-situ networks thus constrain hydrological analyses and climate services.

Nigeria reflects these challenges. Despite extensive surface water resources, water management is constrained by limited hydrometeorological data. Previous studies have identified sparse station distribution and poor maintenance (Ologunorisa, 2010; Skrynyk et al., 2023). Institutional challenges and limited funding have further undermined monitoring capacity, affecting integrated water

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resources management (IWRM) implementation (Onuh & Bassey, 2021; Ngene et al., 2021).

Several internationally supported initiatives have attempted to modernize monitoring in Nigeria. The Nigeria Erosion and Watershed Management Project (NEWMAP) installed automatic weather stations across multiple states, while the Transforming Irrigation Management in Nigeria (TRIMING) project introduced telemetric monitoring systems along major rivers (World Bank, 2021; Muhammad et al., 2025). Automated technologies can enhance hydrological observation and flood forecasting (Hippargi & Patkar, 2020). However, experience across sub-Saharan Africa indicates that externally funded systems often face sustainability challenges after project completion due to limited maintenance capacity, lack of spare parts, and weak institutional support (Lamptey et al., 2024).

The Hadejia River Basin in northwestern Nigeria is an important hydrological and socio-economic system where reliable monitoring is essential. The basin supports extensive irrigation agriculture and major water infrastructure, including Tiga and Chalawa dams, and serves a population exceeding 15 million (Umar et al., 2019). Located within the Sudano-Sahelian zone, the region experiences pronounced seasonal rainfall variability and is vulnerable to both floods and droughts (Hassan et al., 2024; Shuaibu et al., 2022). Effective monitoring is therefore critical for dam operations, irrigation management, and flood risk reduction.

Systematic evaluations of hydrometeorological infrastructure in African basins remain limited. In Nigeria, previous studies have largely examined hydrological processes or climate variability rather than network functionality and sustainability. Furthermore, earlier assessments predate recent modernization initiatives such as NEWMAP and TRIMING. Consequently, limited empirical evidence exists on the current operational status of monitoring networks within major Nigerian river basins, including the Hadejia River Basin.

This study addresses this gap through a field-based assessment of hydrometeorological monitoring infrastructure within the Hadejia River Basin. Specifically, it aims to: (i) inventory existing stations and document their spatial distribution and equipment; (ii) evaluate operational status and functionality; (iii) document recent modernization interventions; (iv) examine operational and institutional challenges through key informant interviews; and (v) assess network adequacy relative to WMO density guidelines.

Methodology

The Hadejia River Basin (HRB) in northwestern Nigeria falls within the jurisdiction of the Hadejia-Jama'are River Basin Development Authority (HJRBDA) and covers parts of Kano and Jigawa states (Figure 1). The basin spans approximately 43,285 km² and lies roughly between 10°30′–13°00′N and 7°00′–10°00′E. It drains northeastward toward the Hadejia-Nguru wetlands, an important floodplain system within the Lake Chad Basin. The drainage network, shown in Figure 1, comprises the Hadejia River and its tributaries.

The region falls within the Sudano-Sahelian climatic zone, characterized by a distinct wet season (May-September) and dry season (October-April). Mean annual rainfall ranges from 600 to 1000 mm, with high interannual variability (Hassan et al., 2024). Major water infrastructure within the basin includes Tiga Dam, Chalawa Gorge Dam, and the Hadejia Valley Irrigation Project, making reliable hydrometeorological monitoring essential for reservoir operations, irrigation management, and flood forecasting.

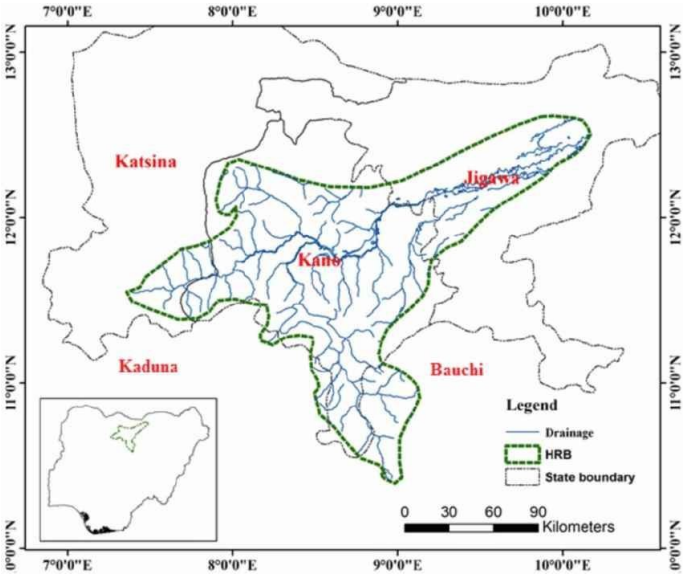


Figure 1: Hadejia River Basin drainage map. Adapted from Umar et al. (2019, p. 186)

Reconnaissance Survey

A reconnaissance survey was conducted over seven days in February 2024 to familiarize with the study area, identify monitoring stations, and establish stakeholder contacts. The survey involved visits to HJRBDA headquarters, relevant state ministries, and selected station locations. Stations selected were those listed in the HJRBDA official monitoring inventory,

comprising all known operational and recently rehabilitated stations: headquarters in Kano, Tiga Dam, Chalawa Gorge Dam, and Auyo Barrage, representing manual, automatic, and telemetric infrastructure types. Introductory letters secured access permissions.

Sampling Strategy

A purposive census approach included all hydrometeorological stations under HJRBDA jurisdiction, as the study aimed to assess the entire network rather than a statistical sample. Snowball identification was also applied, whereby station attendants and agency officials directed researchers to additional installations not initially listed in official records.

Data Collection

Data were collected between March and September 2024 using a mixed-methods approach combining field measurements, direct observation, document review, and key informant interviews.

Quantitative Data

At each station, the following were recorded: (i) geographic coordinates using a Garmin eTrex 10 GPS (±3 m accuracy); (ii) enclosure dimensions; (iii) equipment inventory; and (iv) operational status. Operational status was classified as: functional (instruments operating normally), partially functional (some instruments defective), or non-functional (instruments abandoned).

Table 1: Summary of assessed hydrometeorological stations, equipment, and operational status

Station	Type	Key Equipment	Operational Status	Observations
HJRBDA Headquarters, Kano	Manual	Stevenson screens (2), Class A pan, rain gauge, sunshine recorder	Fully functional	Rehabilitated by NIMET (2018); continuous 6-year record; rain gauge improperly fixed
Tiga Dam	Manual	Sunshine recorder, Class A pan, cup anemometer, wind vane	Fully functional	Excellent equipment condition; all instruments operational
Chalawa Gorge Dam	Manual + AWS	Wind vane, anemometer (faulty), sunshine recorder (non-functional), Stevenson screen (damaged), AWS	Non-functional	Both manual and AWS abandoned; vegetation overgrowth; no data collection
Auyo Barrage (TRIMING)	Telemetric	Multi-parameter water quality and quantity sensors, rain gauge	Functional	Real-time data transmission; >23 installations along river system
Auyo Barrage (NEWMAP)	Automatic	Weather sensors, data logger	Uncertain	Installed but operational status was unclear at time of visit

Source: Author's compilation, 2025

Qualitative Data

Qualitative information was obtained through structured field observations and semi-structured interviews with station personnel. A standardized checklist documented site conditions, including vegetation encroachment, maintenance evidence, enclosure integrity, and security. Photographs were taken to visually document station conditions.

As shown in Table 2, semi-structured interviews (45-60 minutes) were conducted with three technical staff responsible for station operation. Discussions covered station history, maintenance practices, data management procedures, modernization interventions, and operational challenges. Interviews were audio-recorded with consent and later transcribed for analysis.

Table 2: Profile of Key Informant Interview Participants

Category	Location	Qualification	Years of Experience
Hydrologist (Site Engineer)	Chalawa Dam	BSc Geography	5
Hydrologist (Site Engineer)	Auyo Barrage	BEng (Civil)	>10
Hydrologist (Site Engineer)	Tiga Dam	HND Agric Tech	11

Source: Author's compilation, 2025

Document Review

Supporting information was obtained from agency records, station logbooks, and project documents from NEWMAP and TRIMING, together with relevant publications from the Nigerian Meteorological Agency (NIMET) and HJRBDA. These materials provided contextual information on station installation history, rehabilitation efforts, and institutional responsibilities for monitoring.

Data Analysis

Quantitative Analysis

Station inventory data were compiled in Microsoft Excel and analyzed using descriptive statistics to summarize station distribution, equipment composition, and operational status. Geographic coordinates were imported into ArcGIS 10.8 to generate a spatial distribution map of monitoring stations within the basin.

Qualitative Analysis

Interview transcripts and field observations were analyzed using thematic analysis. Data were coded manually through an iterative process that identified recurring patterns and grouped into four analytical categories: (i) operational challenges (e.g., equipment failure, spare-part shortages, staffing limitations); (ii) institutional factors (e.g., funding constraints and maintenance practices); (iii) effects of modernization interventions; and (iv) suggested improvements to monitoring operations. Representative quotations are presented in the results to illustrate key themes.

Photographic records collected during field inspections were organized by station and used to corroborate observational assessments of equipment condition and site maintenance.

Ethical Considerations

Verbal informed consent was obtained from all interview participants after explaining study objectives and their right to withdraw. Due to the small number of technical personnel within HJRBDA, participants were informed that complete anonymity could not be guaranteed; all agreed to participate. Institutional approval was obtained from Bayero University Kano, HJRBDA, and the Kano State Science and Technical Board.

Results/Findings

Overview of HJRBDA Hydrometeorological Stations

Field investigations identified four primary HJRBDA-managed stations: Headquarters (Kano), Tiga Dam, Chalawa Gorge Dam, and Auyo Barrage. The study also documented over 23 telemetric installations under the TRIMING project along the Hadejia River system. Figure 2 shows the spatial distribution of these stations, together with other monitoring facilities within a 100 km radius, including stations operated by NIMET, NIHSA, and educational institutions. Stations exhibited considerable variation in infrastructure quality, equipment condition, and operational status.

The spatial distribution of monitoring stations in figuree 2 reveals a clear clustering around major water infrastructure (Tiga and Chalawa dams, Auyo Barrage) and the HJRBDA headquarters in Kano, with limited coverage in the northern and eastern portions of the basin.

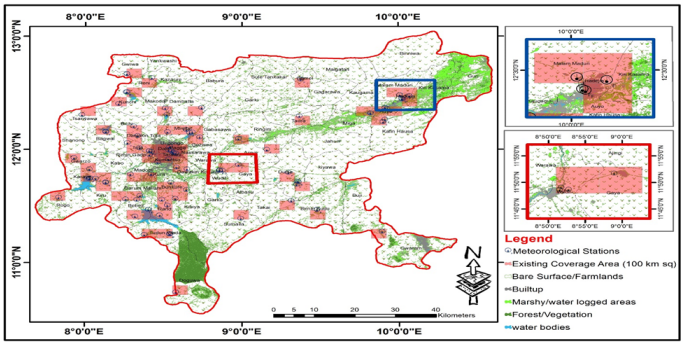


Figure 2: Spatial distribution of hydrometeorological monitoring stations within 100km radius of the Hadejia River Basin, Northwestern Nigeria.

HJRBDA Headquarters Station, Kano

The HJRBDA Headquarters station (Hotoro, Kano) occupies 20×20 m² in a densely populated area. Rehabilitated by NIMET in 2018, it has maintained consistent functionality with continuous records for over six years. The station contains two Stevenson screens with thermometers, a maintained Class A evaporation pan, and a Campbell-Stokes sunshine recorder (lacking recording cards). A standard bronze rain gauge (Figure 3) was improperly fixed, potentially compromising catch accuracy. Based on weather elements measured and dimensions, this facility met WMO (2017) criteria for a "good" station (Garba & Abdourahamane, 2023).



Figure 3: Improperly placed rain gauge at HJRBDA Headquarters, Kano (July 2024)

Tiga Dam Station

The Tiga Dam station, relocated from the dam embankment, is downslope adjacent to the administrative block. All equipment was functional as shown in figure 4 and 5: Campbell-Stokes sunshine recorder with cards in place, well-maintained Class A evaporation pan, cup counter anemometer contrasting with faulty anemometers elsewhere, and unobstructed wind vane.



Figure 4: Functional cup counter anemometer at Tiga Dam (July 2024)



Figure 5: Wind Vane at Tiga Dam (July 2024)

Chalawa Gorge Dam Station

Chalawa Gorge Dam presented a stark contrast to Tiga, with both its manual station and NEWMAP-installed Automatic Weather Station (AWS) completely non-functional at the time of assessment.



Figure 6: Automatic Weather Station at Chalawa Gorge Dam with overgrown vegetation (September 2024)

3.4.1 Manual Station

The manual station contained a wind vane in good physical condition, but all other instruments were non-operational. The cup counter anemometer appeared intact but had not been serviced. The sunshine recorder lacked recording cards and showed no evidence of recent use. The Stevenson screen had deteriorated, damaged by prolonged exposure to solar radiation and rainfall, with no thermometers inside. While the rain gauge was physically intact, the Class A evaporation pan contained only residual rainwater rather than being filled for routine measurements, indicating complete abandonment of manual data

collection.

Automatic Weather Station

Adjacent to the manual station, a separate enclosure housed an Automatic Weather Observing System (AWOS) installed by the NEWMAP project. The equipment appeared sophisticated; comprising a data logger powered by a large automotive battery with capabilities for remote data transmission and local data download. However, the station exhibited critical operational failures: the enclosure was inaccessible due to dense vegetation overgrowth, and interviews confirmed that no readings were being taken. A KII participant described the station as "promising but abandoned," reflecting sustainability challenges documented in donor-funded monitoring projects across sub-Saharan Africa (Lamptey et al., 2024).

Auyo Barrage Installations

The Auyo Barrage site in Jigawa State had two distinct monitoring installations: a TRIMING telemetric system and a NEWMAP installation.

TRIMING Telemetric Devices

The Transforming Irrigation Management in Nigeria (TRIMING) project, a Federal Ministry of Water Resources initiative implemented in collaboration with the World Bank, has installed telemetric devices at strategic locations along the Hadejia River system, primarily mounted on bridges. These automatic instruments measured and transmitted hydrometeorological data in real-time using radio technology.

Parameters captured by the instrument in figure 7 included water depth, turbidity, water and air temperature, evaporation, inflow and outflow volumes, dam discharge rates, and water released for end-users. More than 23 such installations, accompanied by rain gauge stations, were documented along the Hadejia River system. According to KII participants, this network supported water budgeting, input-output management, user demand assessment, and flood control within the basin. This finding contrasts with Ologunorisa (2010), who reported insufficient hydrometeorological stations along the Lower Benue River, suggesting that recent investments may be addressing historical network deficiencies in the Hadejia Basin.



Figure 7: TRIMING telemetric devices at Auyo Bridge (June 2024)

NEWMAP Installation

Approximately 100 meters from the TRIMING installation, a separate NEWMAP-funded station was documented. Similar to the Chalawa AWS, this installation was designed to capture weather and hydrological information specific to barrage operations. However, its operational status at the time of visit was uncertain, with no evidence of routine data collection. The operational characteristics of all assessed stations are summarized in Table 1

Key Informant Interview Findings

Thematic analysis of KII transcripts revealed consistent patterns regarding challenges facing hydrometeorological monitoring in the basin.

Maintenance Challenges

All three KII participants identified inadequate maintenance as the primary constraint to sustained station operation. At Chalawa, the site engineer attributed the abandonment of both manual and automatic stations to "lack of routine maintenance and absence of spare parts." The Tiga Dam engineer noted that while their station remained functional due to dedicated staff efforts, they lacked formal budgetary support for preventive maintenance.

Institutional Factors

Participants described a weak institutional culture of data management. The Auyo engineer with over ten years of experience observed that data collection depended on individual commitment rather than institutional systems, noting that when committed staff were transferred, stations often fell into disrepair. Budgetary constraints were universally cited, with all participants indicating that monitoring activities were chronically underfunded.

Impacts of Modernization Interventions

Perspectives on NEWMAP and TRIMING

interventions were mixed. Participants acknowledged the technological upgrading these projects brought, particularly praising TRIMING's real-time data capabilities. However, concerns were raised about sustainability. The Chalawa engineer noted that "NEWMAP installed the equipment but did not train us on maintenance, and now we cannot fix it when problems arise." This finding aligned with the observed abandonment of the Chalawa AWS despite its sophisticated equipment.

Data Utilization

Despite the challenges, participants at functional stations (Kano HQ, Tiga, TRIMING sites) reported that data were actively used for dam operations, irrigation scheduling, and flood warnings. The Tiga engineer described using rainfall and evaporation data to inform reservoir release decisions, while TRIMING data were reportedly transmitted to the Federal Ministry of Water Resources for basin-wide planning.

Discussion

Inventory, Spatial Distribution, and Network Adequacy

Relative to the basin's area of approximately 43,285 km², the number of operational stations identified (four primary HJRBDA stations plus the TRIMING telemetric installations) is low. The resulting station density falls below the World Meteorological Organization (WMO) guideline of one station per 575 km² for comparable climatic regions (WMO, 2017). Similar deficiencies have been reported across sub-Saharan Africa (Dinku, 2019; Dinku et al., 2018) and in Nigeria's hydrometeorological network (Ologunorisa, 2010; Skrynyk et al., 2023). The concentration of monitoring facilities around major dams suggests that the network historically developed to support infrastructure operations rather than basin-wide environmental monitoring. Sparse spatial coverage limits the availability of ground observations required for hydrological model calibration and validation of satellite-derived products (Chen et al., 2017; Dasgupta et al., 2024; Oudin et al., 2025). Consequently, large portions of the basin remain effectively ungauged, constraining efforts to support integrated water resources management.

Overall, the current monitoring network falls below recommended WMO station density guidelines, limiting the availability of spatially representative hydrometeorological observations. Uneven station distribution results in significant data gaps across portions of the basin, reducing the capacity for basin-wide hydrological assessment and coordinated water management.

The implications extend to climate monitoring and adaptation planning. Long-term ground observations are essential for detecting hydroclimatic trends and validating satellite-based climate products (Maidment et al., 2017). Strengthening monitoring infrastructure therefore remains a critical component of improving environmental information systems in semi-arid regions.

Sustained improvement will require not only expansion of monitoring infrastructure but also institutional integration of monitoring activities into routine operational frameworks. Previous studies emphasize that long-term sustainability of monitoring networks depends on consistent maintenance, technical training, and stable funding arrangements (Bliefernicht et al., 2019).

Equipment Functionality and Operational Status

The operational condition of stations varied considerably across the basin. While the stations at Tiga Dam and the HJRBDA headquarters remained functional, the station at Chalawa Gorge Dam was non-operational at the time of inspection. Such uneven functionality reflects a broader pattern reported in African hydrometeorological networks, where isolated operational stations exist within otherwise degraded monitoring systems (Dinku, 2019; Lamptey et al., 2024).

The continued operation of the Tiga station indicates the importance of local technical capacity and personnel commitment in maintaining monitoring infrastructure. Similar observations have been reported in the WASCAL regional monitoring network, where sustained station operation depended heavily on trained personnel responsible for routine maintenance (Bliefernicht et al., 2019). Conversely, the non-functional status of the Chalawa station illustrates the vulnerability of monitoring systems when maintenance capacity and technical training are insufficient, particularly for automated installations that require periodic calibration and servicing (Patro & Bartakke, 2025).

Modernization Initiatives and Institutional Integration

Recent modernization initiatives, particularly through the NEWMAP and TRIMING projects, demonstrate ongoing investment in hydrometeorological infrastructure in Nigeria. The TRIMING installations along the Hadejia River represent a substantial expansion of monitoring capacity and indicate broader regional initiatives aimed at strengthening environ mental observation systems (Kaspar et al., 2015).

However, the contrasting operational status of TRIMING installations and the NEWMAP station at Chalawa suggests that technology deployment alone does not guarantee sustained functionality. Successful monitoring networks require long-term institutional arrangements that include technical training, maintenance funding, and integration of data into operational decision-making processes. Similar conclusions have been reported in assessments of monitoring programs across Africa, where sustainability depends on continuous institutional support rather than short-term project implementation (Lamptey et al., 2024; Wali et al., 2025).

Institutional and Operational Challenges

Key informant interviews identified maintenance limitations and funding constraints as the principal barriers affecting monitoring operations. Participants emphasized that routine maintenance, spare-part availability, and calibration activities are often constrained by limited operational budgets. Similar institutional challenges have been documented within Nigeria's water sector, where funding allocations for monitoring and maintenance remain insufficient relative to operational needs (Onuh & Bassey, 2021).

Weak institutional structures for data management further complicate monitoring efforts. When monitoring activities depend primarily on individual initiative rather than formalized institutional procedures, station functionality becomes vulnerable to staff transfers or changes in administrative priorities. Such institutional fragility has been identified as a major barrier to effective implementation of integrated water resources management (IWRM) in several African river basins (Martins et al., 2025; Ngene et al., 2021).

Reliable monitoring systems are also critical for flood forecasting and climate risk management in the Sudano-Sahelian region, which is characterized by high hydroclimatic variability (Hassan et al., 2024; Shuaibu et al., 2022). Inadequate monitoring networks therefore limit the availability of data needed for effective disaster preparedness and water resources planning.

Conclusion

This study evaluated the hydrometeorological monitoring infrastructure of the Hadejia River Basin Development Authority (HJRBDA) through field inspection and key informant interviews conducted in 2024. The findings revealed uneven operational performance across the basin's monitoring network. While the stations at Tiga Dam and the HJRBDA headquarters remained operational and the TRIMING telemetric installations were actively transmitting real-time data, the monitoring station at Chalawa Gorge Dam, including the NEWMAP-installed automatic system, was non-functional at the time of assessment.

Relative to the basin's spatial extent of approximately 43,285 km², the number of operational stations remains significantly below WMO recommendations for comparable climatic regions. Interviews with station personnel identified several persistent constraints affecting monitoring sustainability, including inadequate maintenance capacity, absence of dedicated operational budgets, limited availability of spare parts, and insufficient technical training. These factors indicate that station functionality often depends on individual staff initiative rather than institutionalized monitoring systems.

Recent modernization initiatives have expanded the technological capacity of the monitoring network, particularly through automated installations under TRIMING and NEWMAP. However, the contrasting outcomes observed across stations highlight that technology deployment alone is insufficient to ensure sustained monitoring performance. Long-term functionality depends on the integration of monitoring infrastructure into institutional operations through consistent maintenance, technical capacity development, and stable funding arrangements.

Strengthening hydrometeorological monitoring in the Hadejia–Jama'are Basin is therefore essential for improving water resources management, climate monitoring, and disaster risk reduction in the Sudano-Sahelian region.

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