

## Surface water resources management along Hadejia River Basin, northwestern Nigeria

Da' u Abba Umar<sup>a,\*</sup>, Mohammad Firuz Ramli<sup>b</sup>, Ahmad Zaharin Aris<sup>c</sup>, NorRohaiza Jamil<sup>b</sup> and Abubakar Ibrahim Tukur<sup>d</sup>

<sup>a</sup> Department of Environmental Sciences, Faculty of Science, Federal University Dutse, Dutse, Nigeria

<sup>b</sup> Faculty of Environmental Studies, Universiti Putra Malaysia UPM, 43400 Serdang, Selangor, Malaysia

<sup>c</sup> Environmental Forensic Research Centre, Faculty of Environmental Studies, Universiti Putra Malaysia UPM, 43400 Serdang, Selangor, Malaysia

<sup>d</sup> Department of Geography, Kano University of Science and Technology Wudil, Kano, Nigeria

\*Corresponding author. E-mail: abbaumar.d@fud.edu.ng

### Abstract

The current review has unveiled the spatial disparity of the surface water resources availability between the upstream and downstream of the Hadejia River Basin (HRB). The surface water resources are more abundant in the upstream areas of the basin. Although rainfall and temperature dynamics are identified as the major reason for these spatial variations, other important factors include the differences in the geological formation and the land use changes. Furthermore, the differences in the geological formations between the upstream and downstream areas have further widened the disparities in the surface water resources available across the basin which are motivated by the differences in the rate of infiltration. The combined effects of these factors affect both spatial availability and the quality variation of the surface water resources. However, as per this review, there is no single integrated study reported to have aimed at addressing the problems of water resource excesses, deficiencies and/or pollution throughout the basin. To address the problem of water pollution, floods, and droughts, the current review recommends the use of riverbank filtration (RBF), aquifer recharge and recovery (ARR) and rainwater harvesting.

**Key words:** climate variability, resources management, river basin, surface water

### INTRODUCTION

Water is significant to life, it is the next important resource after oxygen and this makes it indispensable in all aspects of human endeavour (Ahmadi & Moradkhani 2019; Falkenmark 2013). For this reason, it is deemed important for any meaningful sustainable development initiatives. In drier regions of the world (like the case at hand), rainfall unreliability and the resultant surface water insufficiencies have necessitated groundwater exploration despite huge investment (Abdulhamid 2014; Mehra *et al.* 2016). In view of this increasing surface water resources predicament, a substantial number of people living in sub-Saharan Africa are gradually shifting to groundwater sources for a potable water supply (Kumar *et al.* 2007). Instances were reported from many African countries

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (<http://creativecommons.org/licenses/by/4.0/>).

where the insufficiency of surface water has necessitated the shift to groundwater sources for freshwater supply. In Ghana, Niger and Botswana, for example, groundwater accounts for 47.56%, 71.43% and 50% of their total freshwater sources, respectively (Xu & Usher 2006; Ghana Statistical Service 2012; Elisante & Mazuka 2016; Nakoma *et al.* 2016). In Nigeria, surface water quantity and quality deterioration, inadequate water supply by water providers, increased rate of population growth and, above all, the consequence of climate change has resulted in increasing demand for freshwater resources from the negligible groundwater sources which was estimated at only 28.90% of the total fresh water of the country (Akujeze *et al.* 2003). In the semi-arid region of northern Nigeria where the Hadejia River Basin is located, the interplay of climatic, geological and anthropogenic characteristics makes surface water virtually inadequate, and many people have been forced to invest and venture into groundwater resources exploitation for domestic and agricultural use (Dammo *et al.* 2015; Tukur *et al.* 2016).

Despite the indispensability of water for human survival, several millions of people have been projected to face freshwater scarcity in this current century unless something serious is done to curtail the magnitude of this water resources predicament (Elias *et al.* 2015). It is worth mentioning that those projected to face water scarcity are mostly people relying on various rivers for their water supply in arid and semi-arid areas of the world (Ifabiyi & Ojoye 2013; Elsanabary & Gan 2015). In these areas, including northeastern Nigeria, surface water predicament exacerbated by climate extremes, especially droughts and desert advancement, have raised the fear that the area may face serious surface water resources challenges in the foreseeable future (Goes 1999), which will mean low groundwater recharge capabilities.

Hadejia River Basin (HRB) is currently home to nearly 15 million people, hosted and supported by the basin's water resources for their livelihoods. The basin is covered largely by semi-arid and partly by humid climates (Sobowale *et al.* 2010). However, the combined influence of natural and human-induced factors, such as water shortages due to climatic changes, desert encroachment, increased population expansion, rain-fed and irrigation agricultural improvement, coupled with water quality deterioration due to pollution was recognized as the active cause of the widening inconsistency between demand and supply of freshwater resources in the area (Goes 2001). Despite the visible associated water resources complications in the area, the extent of surface water resource availability issues in the basin has not been fully acknowledged (Goes 2001). This is indicated by the inadequate water resources availability research as well as the nonexistence of lasting policies for water resources management (Umar & Ankidawa 2016). Indeed, synergizing water availability and demand in the face of climate variability and rising population are the major challenges in the area.

Explicitly, the paper will

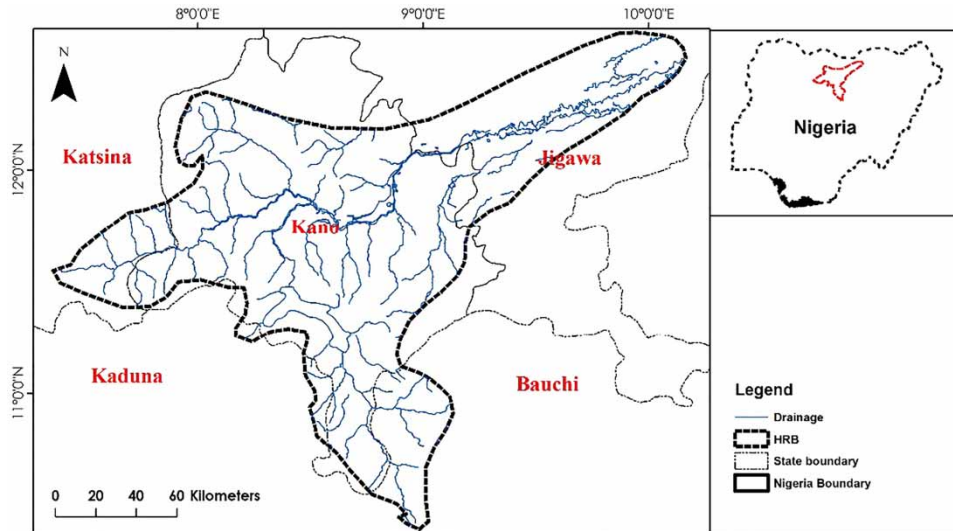
1. indicate areas with surface water scarcity and challenge(s) in the Hadejia River Basin;
2. elucidate the factors linked to the water deficiency and challenges in the Hadejia River Basin;
3. review the major techniques used in water resources studies in the Hadejia River Basin;
4. recommend the way forward on surface water management in the Hadejia River Basin.

---

## THE STUDY AREA

### Geographical background of Hadejia River

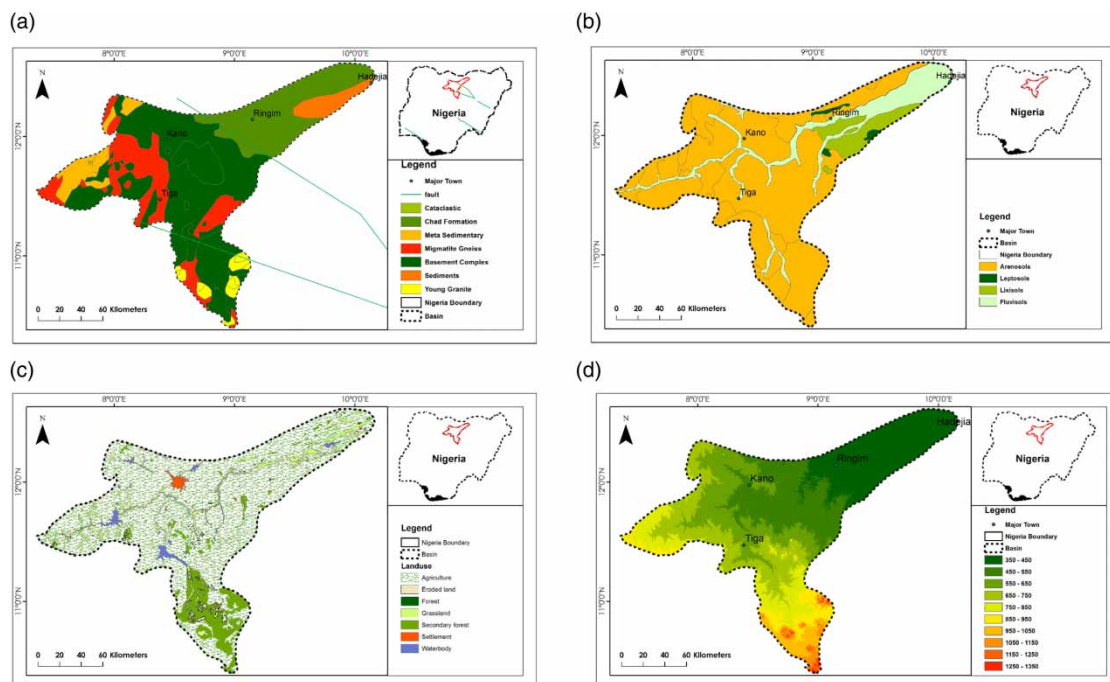
Hadejia River Basin (HRB) located at latitudes 11°32'08.4"N to 12°26'24.8"N and longitudes 8°07'50.0"E to 10°01'50.9"E, has a catchment area of 24,687 km<sup>2</sup>. This river catchment falls largely in the northwestern part of Nigeria (Figure 1), which is referred to as a semi-arid zone in eco-climatic terms (Ikusemoran & Ezekiel 2011). The hydrology of the basin is dendritic in nature (Figure 1). The



**Figure 1** | A map showing the Hadejia River Basin drainage system and the riparian states' boundary.

mean annual flow, peak flow and mean date of peak flow are 1,396 mm<sup>3</sup>/s to 43 mm<sup>3</sup>/s, 597 mm<sup>3</sup>/s to 38 mm<sup>3</sup>/s, and 10 August and 16 September between the upstream and downstream areas of the basin (Umar *et al.* 2018).

The area is known for temporal and spatial variations in rainfall. Annual mean rainfall is about 600 mm in the northeastern parts to 800 mm in the midstream area to 1,000 mm in the extreme south of the basin. Generally, wet periods last between four, five and six months in the extreme north, midstream and the extreme south of the basin, respectively. Consequently, the basin experiences dryness in the rest of the months of the year. Geologically, the basin is underlain by two main geological configurations divided by a boundary (Figure 2(a)). The southern portion of the geological divide is covered by basement complex geological structure of igneous origin, while the



**Figure 2** | A map showing (a) the geology, (b) the soils, (c) the major land use and (d) spatial variation in elevation within Hadejia River Basin.

northeastern portions of the basin are covered by sedimentary Chad formation (Figure 2(a)). The basement complex structure consists of the comparatively shallow weathered mantle on top of solid igneous rocks which hinders surface water penetration. In tune with geological variation, the soil of the area is similarly varied from south to the north of the basin even though it is dominated by a sandy soil fraction (Figure 2(b)). This soil disparity has also contributed to the determination of the rate of infiltration and thus surface and groundwater potentials in the region.

However, the Chad formation sedimentary rocks are made up of unconsolidated sediments. Moreover, there exist deposits of alluvial materials on top of river floodplains that are less difficult to exploit for groundwater exploration using tube wells. Therefore, these main geological structures of the basin were found to influence the spatial availability of surface and groundwater as well as the quality of the waters in the basin. Thus, there is a clear spatial disparity of surface water availability between the two geological formations, with the Chad formation structural region having more groundwater resources and the basement complex region being relatively advantageous in terms of surface water resources availability (Thompson & Polet 2000). Generally, water resources management strategies are essentially scanty. The downstream areas of the basin are currently under pressure and the available groundwater is severely exploited due to the insufficient surface water resources. Additionally, the dominant land use type of the basin is agriculture (Figure 2(c)), which is practised in both rain-fed and irrigated bases. To the south of the basin is higher elevation and the northern part of the basin is dominantly of lower relief (Figure 2(d)).

## Method

An extensive literature survey forms the basis of this study, thus a bibliographic review was based on index citation from various internet sources such as Google scholar citation index and the science citation index expanded (SCIE) databases. This has enabled the evaluation of surface water-related research in the region, handling various issues and viewpoints (Table 1). The studies conducted in this basin profile were mostly related to the impact of river regulation on the river discharge fluctuations in the Hadejia Nguru Wetland (HNWL). Consequently, about 60% of the studies conducted in the entire basin were in the downstream area. Moreover, the downstream area is economically and recreationally important for supporting the flood recession agriculture and hosting the internationally recognized RAMSAR site that accommodates different species of migratory birds.

## Water resource management

A river basin is a physiographic unit composed of interrelated parts and functions. The same geomorphological unit is referred to as a drainage basin, a catchment or a watershed. In a more simple explanation, a river basin comprises the area drained by a river and its tributaries. It provides a convenient natural area within which hydro-meteorological data can be collected and synthesized, from which, other physical and detailed hydrological processes can be meaningfully studied. The fact that its boundaries are stable and well defined is considered and adopted as a convenient spatial unit for water resource development planning (Ayoade 1988). The approach to and strategy for river basin development have undergone some changes over time; however, the primary objective of river basin development, which is the control and effective management and utilization of water resources available within it, still remains unaltered. Humans require water near their settlements and all round the year. However, precipitation follows the laws of nature resulting in a spatio-temporal pattern which many a times is a total mismatch to the human water demand, both in terms of quantity and frequency. Thus, it is very necessary to modify the water cycle to ensure water is available and in acceptable quality, and this is the essence of water resources management (Ayoade 1988). The fundamentals of water resource

**Table 1** | Surface water related studies along Hadejia River Basin

SN	Author and year	Research objectives	Methods	Significant findings	Comments
1	Ahmad <i>et al.</i> (2017)	To evaluate the performance and sufficiency of water use system of KRIP (upstream)	<i>Technique:</i> Meso-level of the new and innovative sufficiency framework	There is no significant attention to water resources management in KRIP and the Kano river entirely, while the rate of consumption is considerably increasing	There is poor management of water usage in KRIP scheme
2	Umar & Ankidawa (2016)	Assessing the effects and threats of climate variations and the ineffective management of wetlands areas (downstream)	<i>Technique:</i> Double mass curve analysis. Sequent, simple linear models (SLM). <i>Data:</i> Secondary data, empirical observations, weather records	The study attributed the conducive condition for Typha grass to thrive on the increased rainfall variability. This unwanted grass now occupies substantial primary farmlands of about 200 km <sup>2</sup> as well the lucrative fishing grounds	The study shows how inadequate management has resulted in the development of Typha grass that has blocked and consumed a substantial area of the basin
3	Tasi'u & Igusi (2016)	Assessing rural water supply situations in Kano region (rural areas along the basin)	<i>Technique:</i> Focus group discussion was employed with the rural settlers	Insufficiency of freshwater supply characterized the rural water supply situations in Kano as stated by about 62.9% of the interviewers, and open wells constitute 41.4% of water supply sources in the area	Water supply in the area can be supplemented through improvement in groundwater development in the locations where it is available and exploitable
4	Sobowale <i>et al.</i> (2014)	Evaluation of groundwater recharge in irrigated lands (entire basin)	<i>Technique:</i> Water level fluctuation (wlf) method	Recharge ranges from 17 to 32 mm daily on the farmland. Average of 8 mm of water is added to storage daily from both rainfall and irrigation. The waterlogging problems that build up salt condition could be ameliorated by the use of surface and groundwater from the farmland	There is a lack of proper management of irrigation water
5	Mustapha <i>et al.</i> (2014)	To assess the spatial variations of surface water pollution and their sources in Kano River (upstream)	<i>Technique:</i> Cluster, discriminant and principal component analysis, one-way ANOVA and post hoc comparison test	Provides an awareness into the magnitude of Kano River water quality and the identification of pollution sources for proper water quality protection and management	Spatial interpolation techniques such as IDW could have been used to present the spatial trend of pollution across the catchment
6	Ikusemoran & Ezekiel (2011)	Monitoring the rapid shrinking of Hadejia Nguru wetland (downstream)	<i>Technique:</i> Descriptive and regression methods. <i>Data:</i> Secondary data, empirical observations, weather records	The decreasing sphere of influence of the wetland can be attributed to climate change, human activities and construction of several dams at the upstream of the river. Frequent monitoring of the area through the use of remotely sensed data and GIS techniques are recommended	The fact that the study involves spatial extent, geographical information system (GIS) could have been employed

(Continued.)

Table 1 | Continued

SN	Author and year	Research objectives	Methods	Significant findings	Comments
7	Odunuga <i>et al.</i> (2011)	To explore the water fluctuations and land use changes within the basin for sustainable agricultural development (entire basin)	<i>Technique:</i> Empirical Thornthwaite model and land use change detection. <i>Data:</i> Climatic data and Landsat satellite imageries	Water balance deficits are manifested in this basin, largely by the increased soil moisture demand. Proper management and adaptation strategies are needed urgently otherwise serious water crises may engulf the basin	This study indicates fear of water crisis due to poor management of basin water resources
8	Sobowale <i>et al.</i> (2010)	Assessing water resource potential of Hadejia River sub-basin (entire basin)	<i>Technique:</i> Double mass curve analysis. Sequent, simple linear model (SLM). <i>Data:</i> Secondary data, empirical observations, weather records	Existing water resource availability in this river sub-basin based on water balance was matched with potential water demand. The water balance potential of the area has indicated that 75% of the river water between Wudil and Hadejia area will likely get exhausted by 2010 as the water use rate will reach 100% by 2018	The study projected the consequences of increased population and urbanization on the water resource availability
9	Barbier (2003)	Determination of the impact of upstream water diversion on downstream activities in Hadejia River Basin (entire basin)	<i>Technique:</i> Economic modelling descriptive and regression methods, <i>Data:</i> Secondary data, empirical observations, weather records	The study demonstrates the negative consequences of increased irrigation in the upstream area on the wetlands areas downstream. This suggests that the increased expansion of the irrigation project is uneconomical. It is also suggested that the initiated controlled flooding regime would perhaps safeguard the groundwater	The study portrays the effectiveness of river basin water management
10	Goes (2002)	To determine the consequences of river regulations on aquatic macrophyte advances and the consequent flooding in the downstream of the river catchment (downstream)	<i>Technique:</i> Descriptive and regression methods. <i>Data:</i> Secondary data, river discharge, observations, weather records	The development of macrophyte weed as a result of change in the river flow was found to aggravate flooding in the area	Has exemplified the effect of river regulation on the downstream flow characteristics
11	Goes (2001)	Determining the consequences of upstream river regulation on downstream users in Hadejia River Basin (entire basin)	<i>Technique:</i> Descriptive and regression methods. <i>Data:</i> Secondary data, empirical observations, weather records	The dams constructed upstream of the river have changed the river flow from ephemeral to perennial. Introducing dry season flow has resulted in the development of weed which retards the smooth flow of river water. Consequently, Hadejia River catchment stopped contributing to the downstream river	The study lacks rigorous methodologies such as the use of hydrological modelling

(Continued.)

Table 1 | Continued

SN	Author and year	Research objectives	Methods	Significant findings	Comments
12	Thompson & Polet (2000)	Examining the impact of human activities on the hydrological characteristics of the Hadejia-Nguru wetlands (downstream)	<i>Technique:</i> Hydrological survey, analyses of flow data and the flood hydrograph. <i>Data:</i> Hydrologic surveys data, river flow data and flood hydrograph	The pattern of land use distribution was found to be influenced by spatial variation in hydrological features. Rice, for example, is favourable cultivation done in the swampy areas popularly known as flood receded. Fishing and animal grazing were also shaped by the hydrological differentiation between the spatial locations	There is a need for assessing the changes in the spatial scope of flood inundation area(s) over time using GIS and RS
13	Goes (1999)	To estimate shallow groundwater recharge in the lower course of the river (downstream)	<i>Technique:</i> Simple descriptive and regression methods. <i>Data:</i> Well records and hydrogeology data	The annual inundation of the flood plain area was the principal source of groundwater recharge. The groundwater table started increasing in the first week after the surface inundation	The study has not taken cognizance of the increased climate variability on the changing flow behaviour
14	Thomas & Adams (1999)	To examine the change that resulted in the past 20 years of Tiga Dam operation (upstream)	<i>Technique:</i> Time series analysis and personal interview	The impacts of Tiga Dam regulations is the change in flow characteristics exacerbated by drought. However, the agricultural practices are gradually adapting to these changes. The adaptation was facilitated by physiological forces related to these changes and the improvement in agricultural innovations and technologies	It is not certain whether the increased production will be sustainable due to increased population and climate change
15	Thompson & Hollis (1995)	To determine the sustainability of the Hadejia-Nguru Wetlands contributions on the socio-economic activities of the inhabitants (downstream)	<i>Technique:</i> Water balance model. <i>Data:</i> Hydro-climatic data	The planned projects intended for the area, if fully implemented, will result in reduction in floods' extent and groundwater storages will drastically reduce due to low recharge. However, an artificial flooding was suggested to facilitate delivery of water to various water users in the upstream and the downstream areas of the basin	The study proposes an artificial flood that will take care of all the water demand/uses within the basin

management anywhere are to ensure fulfilment of water resources where it is needed. This entails minimizing the consequences of water deficit (drought), water excesses (floods) as well as the effects of water pollution.

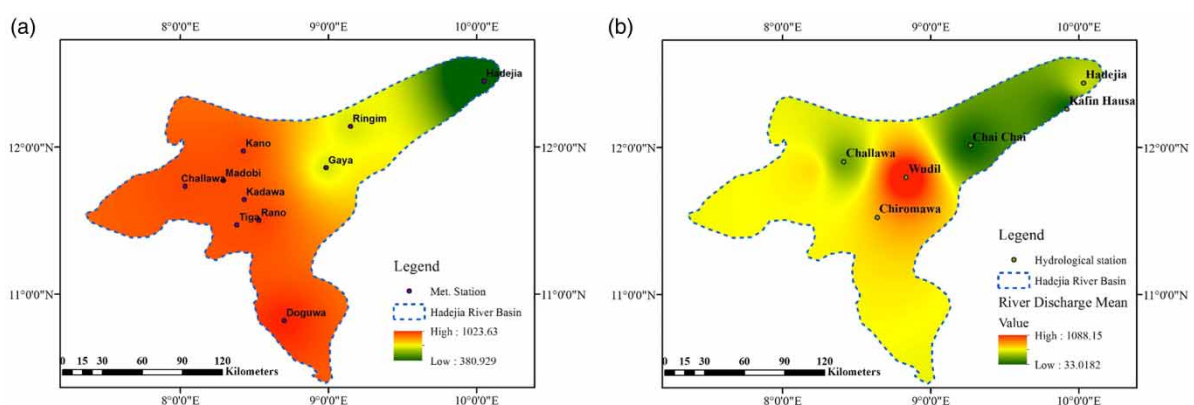
### Surface water availability, dynamics and uses

Surface water resources are characteristically variable in the basin and a number of factors were found to affect the availability and variability, notably, climate variability, geological differences, land use changes, upstream water uses and the development and clearance of weed and silt blockages in river channels. The major factors are briefly discussed below.

### Climate variability (rainfall–runoff scenario along Hadejia River Basin)

The adjustment of the overall climate models is mostly subjective to developed nations, where the data collection network is adequately distributed. However, in the developing countries where the impact of climate variability is more devastating due to low resilience and adaptive capacity, the information on climate change is generally poor (Rizwan *et al.* 2017). There are very little or no available facts in the literature on the impact of climate change on the water resources of Nigeria from the downscaled global climate models, particularly the semi-arid region of the country. Based on the existing climate change scenarios, a decline in rainfall is projected for the West African sub-region ranging from 0.5% to 40% and in the order of 10% to 20% averagely by 2025 (Ahmad & Daura 2019). However, that does not mean a general reduction of the future river water resources of the region; instances are from two different studies from the Volta Basin where an increase in rainfall and river flow was predicted (Andah *et al.* 2003). It is crucial to note that high spatial runoff variability is also predicted, particularly between the upstream and downstream areas of the Hadejia River Basin (Sobowale *et al.* 2010). The mean runoff is higher in Wudil station which is located at the upstream of the basin than in the Hadejia station which is at the downstream of the basin. The mean rainfall and river discharge spatial distribution between the upstream and downstream in the basin is also presented (Figure 3(a) and 3(b)), suggesting higher rainfall and runoff in upstream areas and lower mean rainfall and runoff in the downstream areas of the basin.

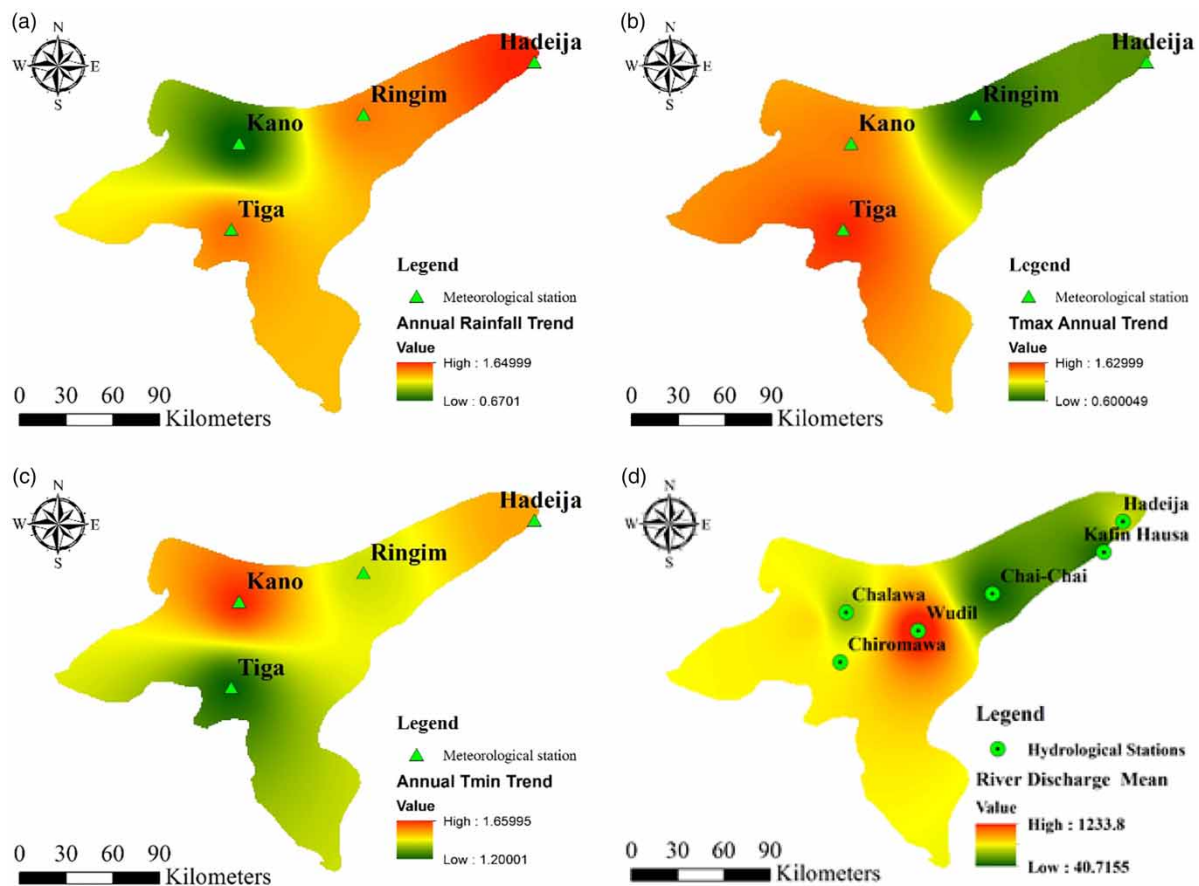
Of all the factors that determine the surface water availability in the region, climatic factors were considered the most important. Rainfall was considered the most important single factor that determines the recharge of both surface and sub-surface water resources (Sobowale *et al.* 2014). However, the effect of temperature on the river water availability is also considerable; the fact that it determines the rate of evapotranspiration, thus seriously affecting the river water, particularly



**Figure 3** | (a) Mean annual rainfall; (b) mean river discharge distribution in the Hadejia River Basin.



impounded river water. A recent empirical study has shown that the impact of rainfall and temperature on river water availability in this basin area is indicated by the disparities and coincidences in the mean rainfall and temperature with the mean of river discharge across the spatial extent of the basin (Umar *et al.* 2018). The spatial interpolation of mean annual rainfall, temperature and river discharge in Figure 4(a)–4(d), modified after Umar *et al.* (2018), indicates that rainfall and river discharge have a positive relationship; however, river discharge decreases with increasing temperature, thus they were negatively correlated.



**Figure 4** | Annual mean rainfall, minimum and maximum temperature and river discharge (modified after Umar *et al.* 2018).

Additionally, population growth across the basin and the lack of sufficient information about the real relationship between the current climate change and surface water resource availability further aggravate the problem of surface water shortages in the region.

### Geological differences

The volume of surface water decreases from the basement complex to the Chad formation area of the basin. Thus, availability of surface water resource is more abundant in the basement complex than in the Chad formation. The Chad formation area of the basin seems to be the principal manageable store of fresh underground water due to the high rate of infiltration, and for that reason groundwater is often considered a rational freshwater resource in the downstream areas of the basin. Conversely, in the basement complex region of the basin, surface water is relatively available even though rapid population growth in association with urbanization has led to severe pollution of the surface water

resources (Mustapha *et al.* 2013, 2014). Consequently, there is increased groundwater exploitation evidenced by increased production of water resources via boreholes, essentially for home usage. However, despite the consideration of groundwater as an alternative source of water for different uses in some parts of the basin, the main worries are for the sustainable supply of the resources considering increased climate and land use changes that can affect both the availability and purity of the available water resource.

### Surface water uses and changes in upstream water uses

The uses of surface water in the areas differ from agriculture, domestic and commercial uses (Thompson & Polet 2000). Despite the numerous uses surface water resource is put to, increased population and urbanization, particularly upstream of the basin, have necessitated the search for and use of groundwater resources as an alternative source of fresh water for various uses. Consequently, boreholes were drilled by private individuals, governments and companies. Thus, there is a fear of overexploitation of the groundwater resource, with its untold consequences.

The most prominent anthropogenic water users in the vicinity of the basin are Kano River Irrigation Project (KRIP), Hadejia Valley Irrigation Project (HVIP) and Kano City Water Supply (KCWS). These three large formal water users all depend on Tiga and Challawa dams for their water supply (Figure 4). The current surface water abstraction by KCWS is estimated at approximately  $30 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ . Still, the surface water intake capacity is expanding (e.g., at Tamburawa downstream of Tiga Dam), so it is likely that the surface water intake by KCWS will increase to  $95 \times 10^6 \text{ m}^3 \text{ y}^{-1}$  within a couple of years. The projected (2025) surface abstraction is  $287 \times 10^6 \text{ m}^3 \text{ y}^{-1}$  (Neville 2005).

The water demand for all the major water users (KRIP, KCWS and HVIP) upstream exceeds planned water allocations (Oyebande 1995). Population growth and change in cropping pattern are some of the reasons for the excessive demand for more water than planned (Oyebande 2003). An increase in these uses decreases the river flow downstream. However, the impact of KCWS and KRIP on annual flows at Hadejia can be mitigated, to a certain extent, when the river flow relation between Wudil and Hadejia is taken into consideration in the management of releases from the dams. A daily or weekly river flow model, using different release hydrographs from the dams, is required to quantify the minimum, mean and maximum impact on river flow at Hadejia when both large upstream users are working at full capacity.

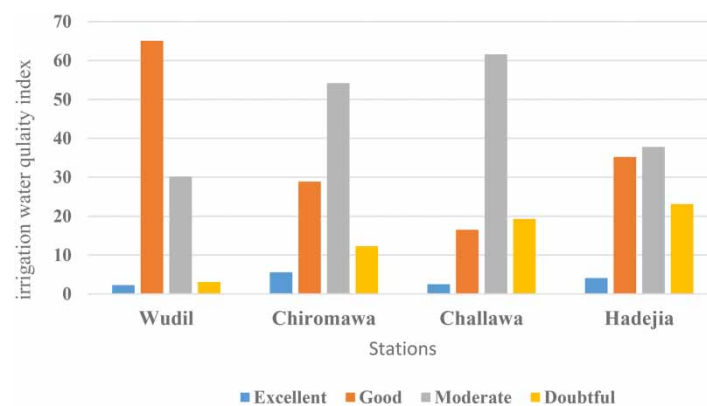
### Appearance and clearance of blockages in river channels

Blockages in channels in the Hadejia River System upstream also affect the flow downstream. In his study, Abdullahi (2009) reported that the basin has been overgrown by an emergence of aquatic weeds belonging to the family *Typhacea*. The flow would increase if the weed and silt blockages upstream were to be cleared. However, the chance that weed and silt blockages upstream will be cleared is small although there was an initiative by people living along the Kafin Hausa River who regularly make efforts to clear blockages in order to facilitate inflow into the river. The effects of the river flow improvements in Kafin Hausa River are normally short-lived (Thompson & Hollis 1995).

### Surface water quality status

The findings of Mustapha *et al.* (2014) revealed that surface water freshness deteriorates more in the drier period than in the wetter period due to the effect of rainfall recharge and dilution capability. Based on the selected surface water quality parameters (pH, temperature, total suspended solids,  $\text{NH}_4 + \text{-N}$ , and  $\text{NO}_3\text{-N}$ ), Tukur *et al.* (2018) investigated the spatial changes of surface

and shallow groundwater quality along Hadejia River Basin. The results showed the order of concentration of surface water pollution class ranging from moderate > good > doubtful > excellent using the Surface Water Quality Index (SWQI) model. As seen from the result (Figure 5), there is no excellent water in all the sampled stations, and doubtful water quality class dominates in all the sample stations. This is in agreement with the previous study conducted by [Mustapha et al. \(2013\)](#). However, despite the dominance of doubtful water quality class, there is still the existence of good and moderate water quality class in the area. The higher concentration of doubtful water quality class at Wudil and Hadejia are attributable to the release of industrial effluent upstream of the latter and the application of fertilizer around the former station. Moreover, the deterioration in water quality at the various points of the river suggests increased urban wastewater releases into the river which, according to [Goes \(2001\)](#), is the main cause of increased freshwater scarcity in the area. Thus, a sustainable monitoring culture should be imbibed to arrest the increasing problem of pollution from industrial and other anthropogenic sources.



**Figure 5** | Suitability of Surface Water Quality Index along Hadejia River Basin.

### Recommended management options

From the foregoing, there seem to be some associated threats attached to surface water resources in the basin, such as the water pollution, water deficiency and the ineffectiveness of the prevailing management choices regarding the prevention of water pollution and the adjustment of water scarcity. To improve both the quality and the availability of surface water resources some management approaches are hereby proposed.

#### Managed aquifer recharge and recovery (MARR)

Managed aquifer recharge (MAR) is reflected as one of the viable means to store the surface water resources when there are water excesses in the wet period ([Brunner et al. 2014](#)). It is principally essential in arid and semi-arid areas such as the northeastern part of Nigeria where HRB is located. This can be achieved through artificial aquifer recharge (AAR) ([Sharma & Ray 2011](#)). The AAR has demonstrated numerous advantages over the commonly used surface water storages, such as the construction of dams which at present is the only method of surface water storage and management within HRB. This method provides many advantages, such as reducing the risk of surface water losses via evaporation, preventing the risk of flooding during the wetter periods, limiting the vulnerability of surface water contamination by animals and human activities, thus the risk of algae blooms is vehemently reduced. In the process of injecting the water, the subsurface provides soil-aquifer

treatment, thus improving the water quality. This stored water can be recovered at and when required through the recovery system.

### **Surface water reclamation and re-use**

Surface water recovery and re-use are considered an option for surface water augmentation and conservation, particularly in drier areas of the world. This can help greatly, regarding the current threats of surface and groundwater exhaustion around most of our urban centres. Reclamation and re-use methods can be used as a substitute to over-dependence on surface and groundwater sources. It can be more practically important in the upstream area where wastewater from industrial areas is frequently produced. In this sense, the wastewater is directed to various urban ponds and other surface water bodies can instead be used to recharge the groundwater after treatment where it can be mixed with ambient groundwater. This will improve the quality of the injected wastewater and in this way reverse the groundwater declination. This improved wastewater will eventually be improved and used again.

### **Rainfall harvesting and detention pond**

This water resources management option has been successfully and popularly practised as supplementary, in some cases, even as a primary water source in semi-arid areas. This technique was necessitated due to the unreliability and insufficiency of rainfall. It was reported to have provided a substantial quantity of fresh water in various regions with wide rainfall variability (Sappa *et al.* 2015). Instances were drawn from Kuwait, with about 12% of the agricultural water demand satisfied via this means; Muscat in Oman fulfilled 27% of its industrial water requirement through rain harvesting; Abha in Saudi Arabia was able to source 11% of its water demand for industrial needs and irrigation agriculture. Similarly, Ali Ain of United Arab Emirates satisfied 16% of its water demand for agriculture using rain harvesting techniques (Zuhair *et al.* 1999; Gereish *et al.* 2015; Sappa *et al.* 2015). Considering the success stories from around the semi-arid areas of the world, this management practice is worth trying in HRB, especially in the downstream areas where the Chad formation structure and rainfall characteristics prevent the accumulation of surface water in reasonable quantities. The detention pond will be useful to numerous households and small communities, especially in the sedimentary formation of the region.

### **Riverbank filtration (RBF)**

Riverbank filtration (RBF) is a procedure where the bed and bank of a river assist in the treatment of river water induced from the river (Ray 2011; Bradley *et al.* 2014). The process takes place when wells are suitably positioned adjacent to the river. The process is completed by pumping to induce the river water to flow towards the well(s) via the bed and bank of the river. Serving as the treatment zones, the bank and bed remove most surface water pollutants (Ray 2012; Dalai & Jha 2014) by joint processes including physical, chemical and biological processes (Singh *et al.* 2010; Sandhu *et al.* 2011; Abdel-Lah 2013). Thus, considering the high rate of surface water pollution in the Hadejia River Basin, riverbank filtration will considerably assist in alleviating the current and potential water scarcity in the area.

### **Managing the floodplain areas**

Managing floodplain entails all operational and remedial tasks that serve as preventive measures for reducing flood impairments, such as early readiness plans, controlling flood and the task of managing the floodplain areas. Managing floodplain was acknowledged as the best and far-reaching technique

for averting impending flood causalities, particularly in areas where there are flood problems (Tanko 2014). Although two main categories of flood control measures exist (structural and nonstructural), in Hadejia River Basin where floods are caused not only by extreme rainfall but also as a result of blockage of river channels, the use of both structural (diversion via reservoir(s), embankments or ditches and channel amendments) and nonstructural measures (flood-proofing, impending flood alerting system and controlling the land use changes) are recommended to regulate the flood runoff.

## DISCUSSION

The study has identified areas that experience surface water scarcity and challenges in the Hadejia River Basin, as well as the factors associated with surface water deficiency and challenges, both spatial and temporal. The factors influencing the spatial disparity are many, however, climate variability, land use change, soil and geological differences are the most important ones (Odunuga *et al.* 2011). Thus, the availability of surface water resources in the Hadejia river basin was found to be spatially variable, with greater availability in the upstream basement complex region (Barbier 2003). The availability decreases northeastward, especially in the Chad formation geological territory. Integrated approaches to surface water management in the basin were suggested.

The analysis of river water balance indicates that the groundwater recharge via indirect ways (stream channel seepage) is nearly 1,535 MCM annually and this happens from Wudil to Hadejia stations which are located within the Chad formation geological region (Barbier 2003). However, the direct recharge to groundwater is about 86 mm and 94 mm computed as mean direct recharge observed in the upstream of Wudil and between Wudil and Hadejia station, respectively. In another development, changes in climate and land use were particularly found to affect the surface water chemistry of the basin (Tukur *et al.* 2018). Evidence is in the spatial differences in dominance of water quality classes with the doubtful water quality class being higher in Wudil and Hadejia (Figure 5), where the latter was influenced by wastewater from municipalities of Kano and Wudil while the former was influenced by the effect of chemical fertilizers used in irrigation plots around Hadejia area.

On the other hand, surface water availability is higher in the upstream areas (stations between Chiromawa and Wudil). Chiromawa is located at the extreme south of the confluence of Kano and Challawa to form the beginning of the Hadejia Basin, where mean rainfall is higher (Figure 4) (Umar *et al.* 2018).

It is pertinent to note that declining surface water resources are expected to pose additional implications in the downstream region where rainfall is less and temperature is constantly high at most times of the year (Dammo *et al.* 2015). Consequently, surface water deficit is obvious in the northeastern portion of the basin which is, moreover, underlain by the sedimentary geological structure. This implies high surface water losses via infiltration. Considering the climatic stress and the increasing water demand, routine assessment of surface water availability is seriously recommended, including simulation and projection of future water resources availability in the basin.

On the whole, the review uncovered the inadequacies, particularly regarding the factors affecting surface water resource availability and management and in respect of the methods and techniques used in conducting the few available studies in the area.

## CONCLUSION

The review has revealed that the availability of surface water resources differs in quantity and quality between the upstream (basement complex) and downstream (Chad formation) areas of the basin.

Surface water resource is more abundant in the basement complex area than in the Chad formation region. Although many factors contributed to these variations, the basic factors are rainfall variability, geological differences and land use changes. In the upstream areas, higher mean rainfall, lower mean temperature and concrete surfaces due to urban expansion as well as the geology are the reasons for surface water availability. However, in the downstream area, lower mean rainfall, higher mean temperature, gradual land use changes and the high losses to groundwater are the explanations for low surface water resources. Finally, the review has recommended the application of riverbank filtration, aquifer recharge and recovery, and rainwater harvesting to harmonize the flood and drought predicaments as well as improving the surface water quality of the river. Similarly, the use of hydro-climatological models is strongly suggested. To this end, there should be an improvement in data collection and management in the entire basin to assist in generating long-term periodic data to help carry out joined up surface water supervision in the area via modelling approaches.

## ACKNOWLEDGEMENTS

The authors are grateful for the contribution of the authorities of the Hadejia River Basin Development Authority, Kano, Nigeria. Also, special thanks go to Abdulkadir Sani of the Department of Geography, Bayero University Kano, Nigeria for enhancing the worth of the figures presented in this paper. The authors have equally contributed to the development of this paper. There is no conflict of interest regarding this paper.

## REFERENCES

- Abdel-Lah, A. 2013 Riverbank filtration for water supply in semi arid environment. *Journal of Engineering Sciences* **41** (3), 840–850.
- Abdulhamid, A. 2014 Drainage, hydrology and water resources. In: *Kano: Environment, Society and Development*, 1st edn, Vol. 1 (Tanko, A. I. & Momale, S. B., eds). Adonis and Abbey, London, UK and Abuja, Nigeria, pp. 21–34.
- Abdullahi, I. L. 2009 *Typaceae in the Kano River Irrigation Project and Management Issues*. PhD Seminar of Geography 9206, Department of Geography, Bayero University, Kano, Nigeria.
- Ahmad, M. T. & Daura, H. A. 2019 Domestic water consumption under unimproved water supply in semi-arid region of northern Nigeria. *Sustainable Water Resources Management* **5** (2), 415–424.
- Ahmadi, B. & Moradkhani, H. 2019 Revisiting hydrological drought propagation and recovery considering water quantity and quality. *Hydrological Processes* **33** (10), 1492–1505.
- Ahmad, M. T., Haie, N., Yen, H. & Tuqan, N. A. 2017 Sufficiency of a water use system: the case of Kano River Irrigation Project, Nigeria. *International Journal of Civil Engineering* **16**, 1–11.
- Akujijeze, C. N., Coker, S. J. L. & Oteze, G. E. 2003 Groundwater in Nigeria – a millennium experience–distribution, practice, problems and solutions. *Hydrogeology Journal* **11**, 259–274.
- Andah, W. E. I., van de Giesen, N. & Biney, C. A. 2003 *Water, Climate, Food and Environment in the Volta Basin*. Contribution to the project ADAPT. Adaptation strategies to changing environments. Available from: <http://www.weap21.org/downloads/ADAPTVolta.pdf>
- Ayoade, J. O. 1988 *Tropical Hydrology and Water Resources*. Macmillan Publishers Ltd, London, UK, p. 189.
- Barbier, E. B. 2003 Upstream dams and downstream water allocation: the case of the Hadejia-Jama'are floodplain, northern Nigeria. *Water Resources Research* **39** (11), 415–426.
- Bradley, P. M., Barber, L. B., Duris, J. W., Foreman, W. T., Furlong, E. T., Hubbard, L. E., Hutchinson, K. J., Keefe, S. H. & Kolpin, D. W. 2014 Riverbank filtration potential of pharmaceuticals in a wastewater-impacted stream. *Environmental Pollution* **193**, 173–180.
- Brunner, N., Starkl, M., Sakthivel, P., Elango, L., Amirthalingam, S., Pratap, C. E., Thirunavukkarasu, M. & Parimalarenganayaki, S. 2014 Policy preferences about managed aquifer recharge for securing sustainable water supply to Chennai city, India. *Water* **6** (12), 3739–3757.
- Dalai, C. & Jha, R. 2014 Review on water treatment techniques used for riverbank filtration. *International Journal of Civil Engineering Research* **5** (3), 221–226.
- Dammo, M., Ibn Abubakar, B. & Sangodoyin, A. 2015 Quantitative analysis of rainfall variations in north-eastern region of Nigeria. *Journal of Agricultural and Crop Research* **3** (5), 67–72.

- Elias, E., Rango, A., Steele, C., Mejia, J. & Smith, R. 2015 Assessing climate change impacts on water availability of snowmelt-dominated basins of the Upper Rio Grande basin. *Journal of Hydrology: Regional Studies* **3**, 525–546.
- Elisante, E. & Muzuka, A. N. N. 2016 Assessment of sources and transformation of nitrate in groundwater on the slopes of Mount Meru, Tanzania. *Environmental Earth Sciences* **75**, 277.
- Elsanabary, M. H. & Gan, T. Y. 2015 Evaluation of climate anomalies impacts on the Upper Blue Nile Basin in Ethiopia using a distributed and a lumped hydrologic model. *Journal of Hydrology* **530**, 225–240.
- Falkenmark, M. 2013 Growing water scarcity in agriculture: future challenge to global water security. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* **371** (2002), 20120410.
- Gereish, M. H., Balke, K. D., El-rayes, A. E. & Mansour, B. M. 2015 Implications of climate change on the groundwater flow regime and geochemistry of the Nile Delta, Egypt. *Journal of Coastal Conservation* **19**, 589–608.
- Ghana Statistical Service 2012 *Housing and Population Census Report*. Ghana Statistical Service, Accra, Ghana.
- Goes, B. 1999 Estimate of shallow groundwater recharge in the Hadejia–Nguru Wetlands, semi-arid northeastern Nigeria. *Hydrogeology Journal* **7** (3), 294–304.
- Goes, B. 2001 Effects of damming the Hadejia River in semiarid northern Nigeria—lessons learnt for future management. In: *Regional Management of Water Resources, Proceedings of a Symposium Held During the Sixth IAHS Scientific Assembly*, Maastricht, Netherlands, pp. 73–80.
- Goes, B. 2002 Effects of river regulation on aquatic macrophyte growth and floods in the Hadejia–Nguru Wetlands and flow in the Yobe River, northern Nigeria; implications for future water management. *River Research and Applications* **18** (1), 81–95.
- Ifabiyi, I. & Ojoye, S. 2013 Rainfall trends in the Sudano-Sahelian ecological zone of Nigeria. *Earth Science Research* **2** (2), 194.
- Ikusemoran, M. & Ezekiel, Y. 2011 Remotely sensed data and geographic information system techniques for monitoring the shrinking Hadejia–Nguru Wetlands, Nigeria. *Lagos Journal of Geo-Information Sciences* **1** (1), 43–52.
- Kumar, M., Kumari, K., Ramanathan, A. L. & Saxena, R. A. 2007 Comparative evaluation of groundwater suitability for irrigation and drinking purposes in two intensively cultivated districts of Punjab, India. *Environmental Geology* **53**, 553–574.
- Mehra, M., Oinam, B. & Singh, C. K. 2016 Integrated assessment of groundwater for agricultural use in Mewat District of Haryana, India using Geographical Information System (GIS). *Journal of the Indian Society of Remote Sensing* **44**, 747–758.
- Mustapha, A., Aris, A. Z., Juahir, H. & Ramli, M. F. 2013 Surface water quality contamination source apportionment and physicochemical characterization at the upper section of the Jakara Basin, Nigeria. *Arabian Journal of Geosciences* **6** (12), 4903–4915.
- Mustapha, A., Aris, A. Z., Yusoff, F. M., Zakaria, M. P., Ramli, M. F., Abdullah, A. M., Kura, N. U. & Narany, T. S. 2014 Statistical approach in determining the spatial changes of surface water quality at the upper course of Kano River, Nigeria. *Water Quality, Exposure and Health* **6** (3), 127–142.
- Nakoma, O., Chidya, R. C. G., Matamula, S. & Chawinga, C. B. J. 2016 Evaluation of borehole water quality in rural-areas of northern Malawi: Case of Zombwe in Mzimba. *Physics and Chemistry of the Earth* **93**, 55–62.
- Neville, D. F. J. 2005 *Scoping Study of the Kano River Raw Water Supply Intake Structures*. ITAD, Report to DFID Joints Wetlands & Livelihoods Project (DFID-JWL).
- Odunuga, S., Okeke, I., Omojola, A. & Oyebande, L. 2011 Hydro-climatic variability of the Hadejia–Jama’are river systems in north-central Nigeria. In: *Hydro-climatology: Variability and Change. Proceedings of Symposium JHO2*, Melbourne, Australia, 163–168.
- Oyebande, L. 1995 Effects of reservoir operation on the hydrological regime and water availability in northern Nigeria. *IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences* **230**, 25–34.
- Oyebande, L. 2003 *Appraisal of Hydrological Information on the Hadejia Jama’are Komadugu Yobe Basin in Light of JEWEL Project’s Needs*. DFID – Jigawa Enhancement of Wetlands Livelihoods Project.
- Ray, C. 2011 Riverbank filtration concepts and applicability to desert environments. In: *Riverbank Filtration for Water Security in Desert Countries* (Ray, C. & Shamruk, M., eds). Springer, Dordrecht, the Netherlands, pp. 1–4.
- Ray, C. 2012 *Riverbank Filtration: Understanding Contaminant Biogeochemistry and Pathogen Removal*, Vol. 14. Springer Science & Business Media.
- Rizwan, M., Kulshreshtha, V. & Dev, P. 2017 Effects of rainfall factor on hydrogeological system recharge in Bangar Environs: A Middle Part of India. *Bulletin of Pure and Applied Sciences* **36**, 27–43.
- Sandhu, C., Grischek, T., Kumar, P. & Ray, C. 2011 Potential for riverbank filtration in India. *Clean Technologies and Environmental Policy* **13** (2), 295–316.
- Sappa, G., Ergul, S., Ferranti, F. & Sweya, L. N. 2015 Effects of seasonal change and seawater intrusion on water quality for drinking and irrigation purposes in coastal aquifers of Dar es Salaam, Tanzania. *Journal of African Earth Sciences* **105**, 64–84.
- Sharma, L. & Ray, C. 2011 A combined RBF and ASR system for providing drinking water in water scarce areas. In: *Riverbank Filtration for Water Security in Desert Countries* (Ray, C. & Shamruk, M., eds). Springer, Dordrecht, the Netherlands, pp. 29–49.
- Singh, P., Kumar, P., Mehrotra, I. & Grischek, T. 2010 Impact of riverbank filtration on treatment of polluted river water. *Journal of Environmental Management* **91** (5), 1055–1062.
- Sobowale, A., Adewumi, J., Okuofu, C. & Otun, J. 2010 Water resources potentials of Hadejia River Sub-Catchment of Komadugu Yobe River Basin in Nigeria. *Agricultural Engineering International: CIGR Journal* **12** (2), 1–6.

- Sobowale, A., Ramalan, A., Mudiare, O. & Oyeboode, M. 2014 [Groundwater recharge studies in irrigated lands in Nigeria: implications for basin sustainability](#). *Sustainability of Water Quality and Ecology* **3**, 124–132.
- Tanko, A. I. 2014 Water resource development and management. In: *Kano: Environment, Society and Development*, 1st edn, Vol. 1 (Tanko, A. I. & Momale, S. B., eds). Adonis and Abbey, London, UK and Abuja, Nigeria, p. 228.
- Tasi'u, Y. R. & Igusi, E. O. 2016 Assessment of water supply situation in the rural areas of Kano State, Northern Nigeria. *Global Advanced Research Journal of Agricultural Science* **5**, 33–41.
- Thomas, D. H. & Adams, W. M. 1999 [Adapting to dams: agrarian change downstream of the Tiga Dam, Northern Nigeria](#). *World Development* **27** (6), 919–935.
- Thompson, J. R. & Hollis, G. E. 1995 [Hydrological modelling and the sustainable development of the Hadejia-Nguru wetlands, Nigeria](#). *Hydrological Sciences Journal* **40** (1), 97–116.
- Thompson, J. R. & Polet, G. 2000 [Hydrology and land use in a Sahelian floodplain wetland](#). *Wetlands* **20** (4), 639–659.
- Tukur, A. I., Garba, I., Mustapha, A., Umar, D. A. & Sulaiman, W. A. S. 2016 An Overview of Groundwater Quality Studies in Developing Countries. In: *Economic Diversification Through Sustainable Mineral Resources Development, Proceedings of the 52nd Annual International Conference and Exhibition of the Nigerian Mining and Geosciences Society (NMGS)*, Ilorin, Nigeria, 13–18 March 2016.
- Tukur, A. I., Nabegu, A. B., Umar, D. A., Olofin, E. A. & Suleiman, W. N. A. 2018 [Groundwater condition and management in Kano Region, Northwestern Nigeria](#). *Hydrology* **5** (1), 1. Doi: 10.3390/hydrology5010016.
- Umar, A. S. & Ankidawa, B. A. 2016 Climate variability and basin management: a threat to and from wetlands of KomaduguYobe Basin, North Eastern Nigeria. *Asian Journal of Engineering and Technology* **4** (2), 25–36.
- Umar, D. A., Ramli, M. F., Aris, A. Z., Sulaiman, W. A., Jamil, N. R. & Abdulkareem, J. H. 2018 Rainfall irregularities, trends and variations in tropical semi-arid river catchment. *Journal of Hydrology: Regional Studies* **9**, 335–348.
- Xu, Y. & Usher, B. 2006 *Groundwater Pollution in Africa*, 1st edn. Taylor and Francis Group, Leiden, The Netherlands.
- Zuhair, A., Nouh, M. & El Sayed, M. 1999 Flood harvesting in selected Arab states, Final Report No. M31/99, Institute of Water Resources. In: *Integrated Urban Water Management: Arid and Semi-Arid Regions* (Mays, L. W., ed.). UNESCO Publishing, Paris, France and Leiden, The Netherlands, p. 46.

First received 2 April 2019; accepted in revised form 7 August 2019. Available online 26 October 2019