Direct Research Journal of Engineering and Information Technology

Vol. 12(3), Pp. 1 -13, November 2024,

https://journals.directresearchpublisher.org/index.php/drjeit

Research Article
ISSN: 2354-4155

Development of Water Allocation Optimization Model for the Sokoto-Rima River Basin using WEAP

Tunde Abioye[1], Adebayo Wahab Salami[2], and Ayanniyi Mufutau Ayanshola[3]

[1]Department of Civil Engineering, Umaru Ali Shinkafi Polytechnic, Sokoto, Nigeria.
[2]Department of Department of Water Resources and Environmental Engineering, Faculty of Engineering, and Technology, University of Ilorin. Ilorin, Nigeria.
[3]Department of Civil Engineering, Faculty of Engineering, and Technology, University of Ilorin. Ilorin, Nigeria.
Corresponding author: tundeabioyea10@gmail.com

ABSTRACT

Water allocation for the Sokoto-Rima River basin has been modelled and Optimized with the use of WEAP-model. The water demands in the Sub-basins were aggregated to configure the WEAP-model using 2016 as the base year. A reference scenario (2017-2024) was developed from current account through the year 2024. The reference scenario therefore produced a total of 793.4 x 106 m3 as monthly average water demand and a projected yearly water demand accruing to a total of 7,140 x 106 m3 per day through 2024. The projected water supply projected to be 3,939 x 106 m3 with a total of 3,151.1 x 106 m3 unmet water demand per day through year 2024. What if scenarios were built on the reference scenarios to determine the impact of changes in parameters with which the models were calibrated. Population management, Water Management and reduction in irrigation water use and sourcing alternative water sources were the scenarios built, to identify their effect on the water allocation in the basin and how they will reduce the unmet demand in the entire basin as a whole. Projected yearly unmet demand for population management Scenario yielded a total of 272.0 x 106 m3 in 2017 to 4,432.2 x 106 m3 in the year 2056, Sourcing alternative water sources within the basin produced a projected unmet demand of 1,474.8 x 106 m3 as monthly averages for the whole basin, while reduction in irrigation water scenario has projected unmet water demand as 258.5 x 106 m3 in 2017 remained unchanged through 2056. It was discovered that WEAP performed well in optimizing water allocation in the basin studied as the scenarios simulated results impacted on the basin water allocation. Irrigation water use should be reduced through irrigation method change as well as other sources of water be sought and harnessed for improved water supply in the basin, these includes development of small dams to take care of specific purposes in the basin.

Keywords: Optimization, Scenarios, Unmet Demand, Water Allocation, WEAP

Article information
Received 2 October 2024;
Accepted 3 November 2024;
Published 21 November 2024
DOI: https://doi.org/10.26765/DRJEIT16752603

Citation: Abioye T., Salami, A. W., and Ayanshola, A. M. (2024). Development of Water Allocation Optimization Model for the Sokoto-Rima River Basin Using WEAP. Direct Research Journal of Engineering and Information Technology Vol. 12(3), Pp. 1-13.

INTRODUCTION

Adequate supply of water is central to life and civilization. Of the five basic human needs (water, food, health, education, peace), water is a common factor to the other four. Food production as well as most societies' social – economic activities depends on water availability (Federal Republic of Nigeria, 2004). Water resources provide important benefits to mankind, both commodity benefits and environmental values. There are serious challenges facing nations water supply throughout the world and our country, Nigeria is not an exception as it was asserted in the (Federal Republic of Nigeria, 2004) that 'The country (Nigeria) has made considerable investments in water schemes and related activities in addition to being blessed with abundant water resources the desire to improve access to this resource was becoming more and more elusive because of the rapidly increasing in the demand for water. The rise in the demand was outstripping supply due to high population growth rate and coupled with increasing urbanization, and rising living condition as a result of economic growth. Because of the increasing scarcity of water for both economics and environmental benefits and scarcity of the resources required to develop water, economic consideration plays an increasingly important role in public decisions on water projects, reallocation proposals and other water policies (Ariel et al, 2015). The increasing demand for water and the general notion that water is becoming scarce have resulted in a competition among the water users. One of the most serious issues of water management is the question of how to allocate the water resources to guarantee sufficient amount of water for all demands. The balance has to be found between the requirements of the local consumers, the needs for regional development, and the principles of environmental sustainability. Water allocation is the process of sharing a limited natural resource between different regions and competing users. Water allocation is central to the management of water resource (Wang et'al, 2003). It is a process made necessary when the natural distribution of water and its availability fails to meet the needs of all water users – in terms of quantity, quality, timing of availability, or reliability. In simple terms, water allocation is the mechanism for determining who can take water, how much they can take, from which locations, when, and for what purpose (Robert et 'al, 2014). A useful definition of water allocation according to (UN–ESCAP, 2000) is the combination of actions which enables water users and water uses to take or receive water for beneficial purposes according to a recognized system of rights and priorities. The overall objective of water allocation is to maximize the benefits of water to society, which can be further classified as social, economic and environmental in nature. For each classification, there is a corresponding principle: equity, efficiency and sustainability, respectively. Equity means the fair sharing of water resources within river basins, at local, national, and international levels. Equity needs to be applied amongst water users, existing and potential users, and consumers of water and the environment. It is important to have pre-agreed rules or processes for the allocation of water, especially in situations where water is scarce. Such agreements and methodologies should reflect the wishes of those affected sufficiently to be equitably and accountably applied. Efficiency is the economical use of water resources, with particular attention to economic activities, demand management, financially sustainable uses of water resources, and fair compensation for water transfers at all geographical levels. Efficiency is not so easy to achieve, because the allocation of water to users relates to physical delivery or transport of water to the demanding points of use. Many factors are involved in water transfers, one of which is the conflict with equitable water rights. For example, a group of farmers should have permits to use certain amounts of water for agricultural irrigation. Some water for irrigation might be transferred to some industrial uses if policy makers decide to try to achieve an efficiency-based allocation of water. In this case, farmers should receive fair compensation for their losses. Sustainability advocates the environmentally sustainable use of land and water resources. This implies that today's use of water resources should not expand to such an extent that water resources may not be available in the future (Savenije and Van der Zaag, 2000). Water resources comprise surface water (rivers, lakes, and reservoirs), groundwater, floodwater, and, with the advent of new technologies, desalinated water, are an essential input for various economic sectors, such as municipal, industrial, agricultural, hydropower, recreation and environmental. With increased population growth rates, improved life style, and dwindling supplies (both in terms of quantity and quality), the competition over scarce water resources is increasing. It is thus of increasing importance that the existing water resources be allocated more efficiently (Ariel et al, 2014). Two obvious major sources of water supply are surface water and groundwater. Although the complete hydrological cycle is global in nature, a rational and suitable water resources modeling and management unit is needed at the river basin level (McKinney et al., 1999). In order to make good operational decisions regarding solutions to sharing water in a watershed, a fundamental scientific understanding of hydrologic constraints and conditions is required. The need for a water allocation activity arises from demands for water. Where the resources are restricted compared to demands, as is the case for irrigation in some regions, conflicts arise among competing users. In general, water uses can be grouped into various demand groups: water supply for a city, agriculture, hydropower, navigation and other demands including flood storage, recreation, ecological uses and even bulk water export. An operational water allocation plan should be based on the hydrological constraints and linkages between demanding uses and water sources.

The Sokoto-Rima River basin is central to sustainable water supply to part of katsina, Sokoto, kebbi and Zamfara states. The water resources in the basin are already in competition for supply of potable water for the city of Sokoto and other cities in the Sokoto state, Talata mafara and other cities in Zamfara state as well as Irrigation water for Goronyo irrigation projects, Talata mafara and that of kebbi state irrigation projects. This therefore calls for development of a mechanism to optimize the water allocation in the basin. The basin produces enough water during wet season which is capable of taking care of the water need (Daily Trust,2012), but shortages have been witnessed in the different sectors in the region. Irrigation agriculture, coupled with the effort of the nation to increase rice production in the country, provision of adequate potable water for the present and future population as well as ecosystem balance have therefore put pressure on the water resources in the basin, and this however calls for development of water resources optimization model system which will share the water resources in an equitable and sustainable manner within the basin.

METHODOLOGY

The required data have been collected based on their availability at the various places. The monthly flow on the Rima River was collected at the SRRBDA. The flow from river Sokoto was collected at the Zamfara State ministry for water resources while that of the river Ka and other rivers were obtained in Argungu, 2014.

The study area

Sokoto-Rima River Basin is located in the North-Western region of Nigeria, the area is found between latitude 10°04' – 14°00 N and Longitude 3°- 8° 14' E. The area covers a land area of approximately 131,600 km^2 and shares its borders with Niger Republic to the north, and covers Sokoto, Kebbi, Zamfara and large part of Katsina States. It borders Niger State to the South-east, and Benin Republic to the west (Figure 1). The whole basin can be described as Sudan and Sahel Savanna, and it extends beyond the border to Niger republic and the northern part of Benin Republic. The basin topography consists of a vast floodplain (fadama land) and rich alluvial soils that is suitable for the cultivation of different variety of crops. There are also isolated hills (inselberg) and hill ranges scattered all over the area (Ekpoh and Ekpenyong, 2011). The basin is essentially drained by the river Sokoto, a prominent part of Niger river drainage system. The sokoto river rises with its main tributaries, the river 'Ka', Zamfara, and Rima from the 600 to 900 meters high Mashika and Dunia highland areas bordering the eastern part of the basin, and flows down, rather sluggishly down a gentle slope toward the northwest and around Sokoto town, it is joined by the Rima in the north, making a southward swing, collecting the Zamfara and Ka before entering in to the river Niger. The river systems, thus effectively drains the whole basin. At the source areas in the east, the Sokoto river system is only seasonal. However, in the western parts of the basin, the river becomes perennial as it begins to receive substantial ground water contribution to its flow (Abdullahi *et'al,* 2014). The map of the river basin is as shown below (Figures 1 and 2).

Simulation of water balance and allocation is the basis for optimization, thus elements such as water demand/ supply system and their spatial relationship are characterised for the catchment under study. Considering demand sites to be enormous, it has been broadly classified into four categories viz: domestic, Agricultural/irrigational, commercial, and industrial water demand within the entire basin. Current account was declared as 2016 and it served as the baseline for the processes taking place within the basin.

WEAP model was calibrated using existing data withing the Basin and making 2016 as the baseline year / current account. Data used include the per capital water demand in the various sub-catchment in the river basin. For population used in the development of current account, (Table 1) presented the summary as it existed in the model. Irrigation land with respect to water demand within the basin has been presented in (Table 2) and based on this, the whole basins irrigation demand was configured in the WEAP model. Table 3 presented the flow data used in the configuration of current account.

The current population growth rates are presented in section 3.5 According to the JICA report of 2014, growth rates are at 3.03% for Sokoto sub-basin, 3.04% for Katsina sub-basin, 3.17% for Kebbi sub-basin and 3.2% for Zamfara sub-basin. This study therefore considers reduction as well as increase in the population growth rates of 2.5%, 3.2% for Sokoto sub-basin, 2.6%, 3.3% for the Katsina sub basin, 2.8%, 3.21% for Kebbi sub-basin and 3.21%, 3.35% for Zamfara sub-basin. Table 4 shows the growth rates for reference scenario, lower and high population growth scenario for the relevant sections in the river basin.

Currently, the irrigation activities in the entire river basin are not well developed. The total irrigation project implemented in the whole river basin stood at 48,742 ha. It has been reported that only 17,604 ha out of 69,000 ha of the irrigable plots in Goronyo is cultivated leaving a total of 51,396 ha uncultivated. Also, there are 3,440 ha of irrigable land in kebbi which is yet to start functioning

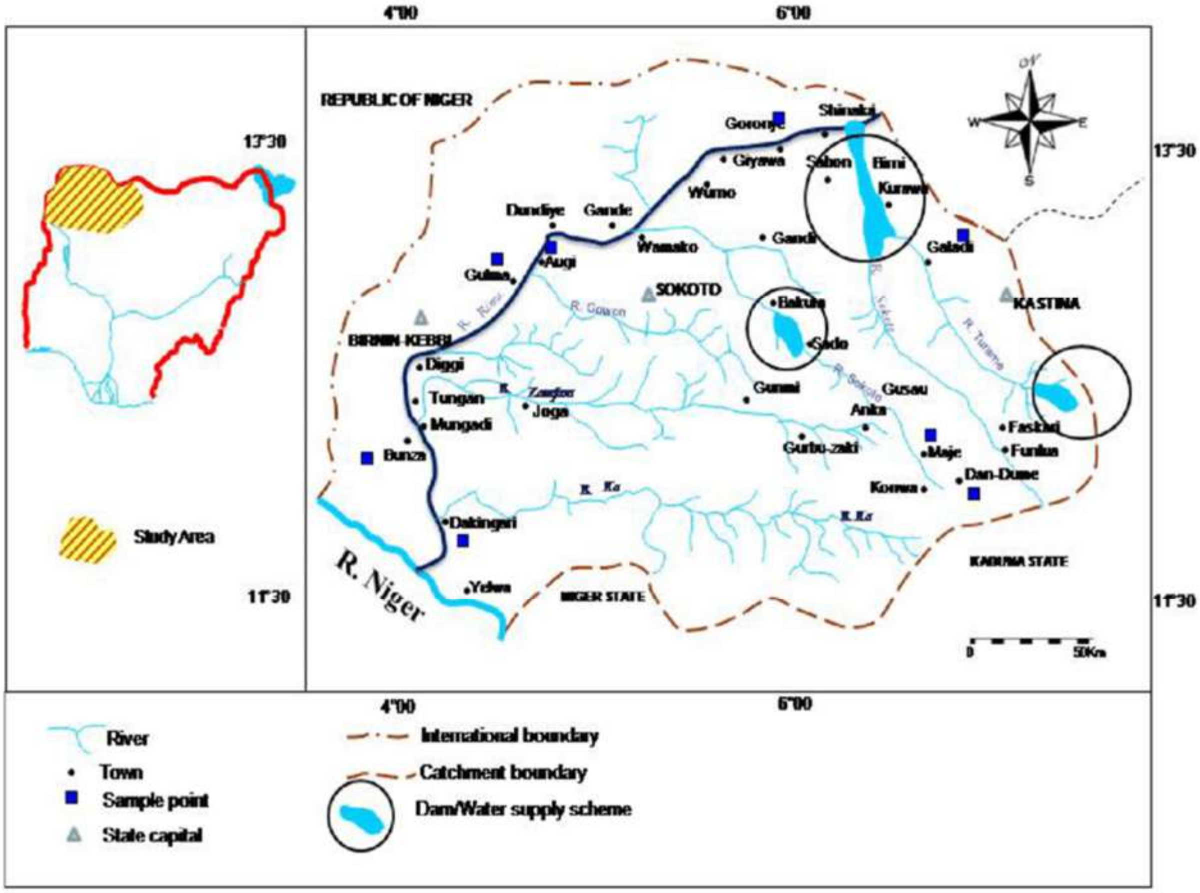

Figure 1: The map of Sokoto-Rima basin, Nigeria.

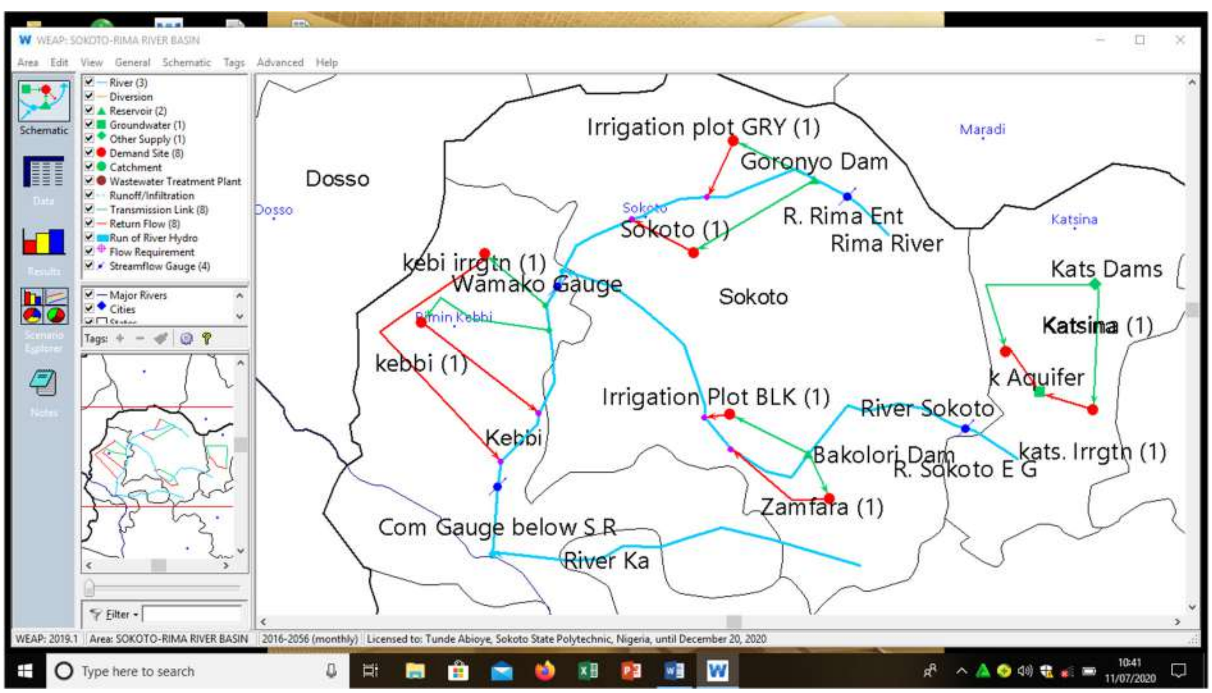

Figure 2: WEAP screen views, menu bar schematic view in the study catchment.

Table 1: Summary of population figures in the sub-catchment of the river Basin.

Districts/ Sub-catchment	Population Million (persons)	Growth rate (%)
Katsina	7831300	3.04
Kebbi	4440000	3.17
Sokoto	4998100	3.03
Zamfara	4515400	3.2
Total	21972206	

Table 2: Irrigated areas and the water needs for the whole basin.

Irrigation projects	Irrigated Area (10^3 m^2)	Water requirement (m^3 /10^3 m^2)
Goronyo Irrigation	176,040	2
kebbi zone	50,020	0.5
Katsina Zone	131,118	1.2
Bakolori Irrigation Project	130,000	1.6

Source: (SRRBA, 2018).

Table 3: Average Monthly River flows (m^3/s).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rima River	56.45	51.44	48.93	46.42	47.67	95.35	101.7	131.7	150.5	117.9	89.07	62.73
River Ka	3.013	2.582	2.41	1.937	2.798	5.38	9.899	13.99	17.86	17	14.42	4.519
River Sokoto	46.75	45.33	45.33	42.5	58.08	80.75	120.4	144.5	149.7	119.6	87.83	56.67

Source: (SRRBA. 2018)

Table 4: Population growth rate assumptions

Description of the Area	Reference Scenario	Low population growth	High population growth
	2016-2056	2017-2056	2017-2056
Sokoto Sub-basin	3.03%	2.5%	3.2%
Katsina Sub-basin	3.04%	2.6%	3.3%
Kebbi Sub-basin	3.17%	2.8%	3.21%
Zamfara Sub-basin	3.2%	3.1%	3.35%

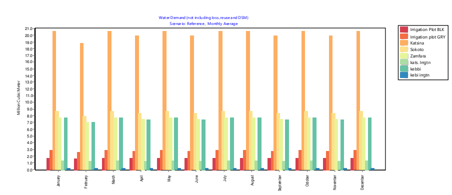

Figure 3: Chart showing the Water demand (Monthly Average) for the whole river basin for current account year 2016

(MOWR, 2018). Taking into consideration the quest for more rice production by the ministry of Agriculture with a view to achieving food sustainability, it is assumed that the whole irrigable plots will be cultivated, this means the total irrigable plots is going to increase to 104,578 ha and this formed the second scenario. Currently the system of irrigation practice in the river basin is predominantly flooding method. This is made possible due to the availability of water through canals. These networks of canals deliver water to the fields where crops are planted. Drainage systems are also available to drain the unutilised water to the streams. In the current system of irrigation, the aggregate water demands per hectares in the sub-basins are 2, 0.5, 1.2 and 1.6m^3 / 10^3m^2 for Goronyo irrigation, kebbi irrigation, Katsina Zone irrigation and Bakolori irrigation project. To address the unmet water demand in the basin a scenario has been created which proposes a reduction in the water allocation to irrigation fields. These are 1.0, 0.25, 0.6 and 0.8 m^3 / 10^3m^2 for Goronyo irrigation, kebbi irrigation, Katsina Zone irrigation and Bakolori irrigation fields. Also, this Scenario incorporated sourcing and utilization of other water sources such as ground water, and wells in katsina and kebbi irrigation fields.

RESULTS

Results of the current account is presented in the (Tables 5, 6, 7 and Figure 3) respectively. The monthly average water demand from each sector of the basin in MCM

Table 5: Monthly Average water demand (MCM) for the current account (2016).

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
Irri BLK	1.8	1.6	1.8	1.7	1.8	1.7	1.8	1.8	1.7	1.8	1.7	1.8	20.8
IrriGRY	2.9	2.6	2.9	2.8	2.9	2.8	2.9	2.9	2.8	2.9	2.8	2.9	34.0
Katsina	20.6	18.8	20.6	19.9	20.6	19.9	20.6	20.6	19.9	20.6	19.9	20.6	242.8
Sokoto	8.7	7.9	8.7	8.4	8.7	8.4	8.7	8.7	8.4	8.7	8.4	8.7	102.2
Zamfara	7.8	7.1	7.8	7.5	7.8	7.5	7.8	7.8	7.5	7.8	7.5	7.8	91.4
kats. Irrgtn	1.3	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	15.7
kebbi	7.7	7.0	7.7	7.5	7.7	7.5	7.7	7.7	7.5	7.7	7.5	7.7	90.8
kebi irrgtn	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.5
Sum	50.9	46.4	50.9	49.3	50.9	49.3	50.9	50.9	49.3	50.9	49.3	50.9	600.2

Source: (WEAP model Authors Computation, 2022).

Table 6: Monthly Average Water Demand $10^6 m^3$ for Reference scenario (2017-2024).

	Jan	Feb	March	April	May	June	July	August	Sep	October	Nov.	Dec.	Sum
Irrigation Plot BLK	2.7	2.4	2.7	2.6	2.7	2.6	2.7	2.7	2.6	2.7	2.6	2.7	31.4
Irrigation plot GRY	4.4	4.0	4.4	4.2	4.4	4.2	4.4	4.4	4.2	4.4	4.2	4.4	51.3
Katsina	25.3	23.1	25.3	24.4	25.3	24.4	25.3	25.3	24.4	25.3	24.4	25.3	297.7
Sokoto	13.2	12.1	13.2	12.8	13.2	12.8	13.2	13.2	12.8	13.2	12.8	13.2	155.7
Zamfara	9.7	8.9	9.7	9.4	9.7	9.4	9.7	9.7	9.4	9.7	9.4	9.7	114.5
kats. Irrgtn	2.0	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	23.8
kebbi	9.8	8.9	9.8	9.5	9.8	9.5	9.8	9.8	9.5	9.8	9.5	9.8	115.3
kebi irrgtn	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	3.8
Sum	67.3	61.5	67.3	65.1	67.3	65.1	67.3	67.3	65.1	67.3	65.1	67.3	793.4

Source: WEAP Model Author's Computation, 2022

Table 7: Projected Yearly water Demand $10^6 m^3$ for (2017-2024) .

	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
Irrigation Plot BLK	20.8	22.9	25.2	27.7	30.5	33.5	36.8	40.5	44.6	282.5
Irrigation plot GRY	34.0	37.4	41.1	45.3	49.8	54.8	60.2	66.3	72.9	461.7
Katsina	242.8	255.2	268.1	281.7	295.7	310.4	325.7	341.6	358.2	2,679.5
Sokoto	102.2	114.0	126.4	139.5	153.3	167.8	183.0	199.0	215.8	1,400.9
Zamfara	91.4	95.0	100.8	106.9	113.3	120.0	127.0	134.3	142.0	1,030.8
kats. Irrgtn	15.7	17.3	19.0	21.0	23.0	25.4	27.9	30.7	33.7	213.8
kebbi	90.8	96.2	102.0	108.0	114.3	120.9	127.8	135.0	142.5	1,037.3
kebi irrgtn	2.5	2.8	3.0	3.3	3.7	4.0	4.4	4.9	5.4	34.0
Sum	600.2	640.7	685.8	733.3	783.6	836.7	892.9	952.3	1,015.1	7,140.5

Source: WEAP Model Author's Computation, 2022

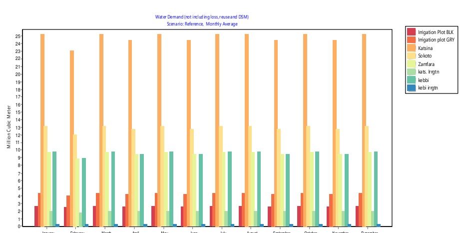

Figure 4: Monthly Average Water Demand $10^6 m^3$ for Reference scenario (2017-2024).

(Million Cubic Meter) were presented. It was therefore observed that for current account the Sokoto, Kebbi, Katsina and Zamfara Municipal water demand were 102.2, 90.8, 242.8and 91.4 MCM respectively. The sum of the monthly averages as obtained in the current account for the irrigation activities for, Bakolori, Goronyo, Katsina irrigation and Kebbi irrigation were 20.8, 34.0, 15.7 and 2.5 MCM respectively. The total water demand for current account year for the whole basin in 2016 is 600.2 MCM. Supply delivered owing to the available resources in the basin in the current account stood at 341.7 MCM which is 56.93% of the water demand for the basin. Unmet water demand therefore is observed to be 258.5 MCM.

Water demand for the whole basin

The results of total water demand not including loss and unaccounted for water is as shown in the (Table 6 and Figures 4, 5 and 6, 7). The projected water demand for all water demand sectors within the basin is presented in (Table 7). Yearly water demand for irrigation agriculture

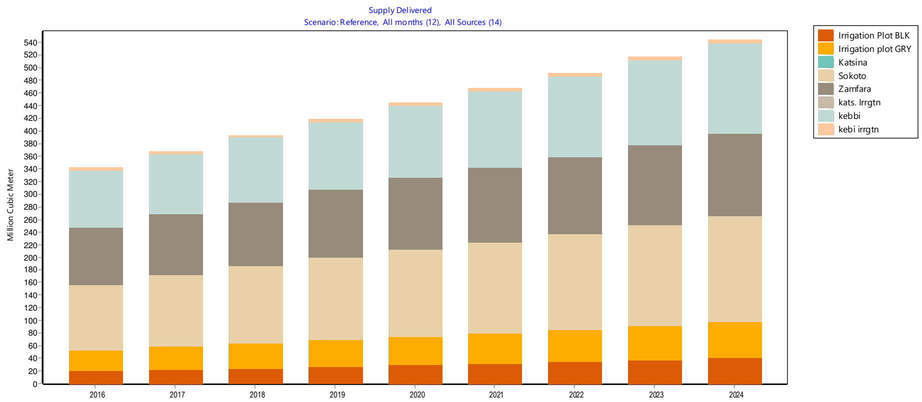

Figure 6: The chart of Supply delivered for all the demand sites in the basin as projected (2017-2024).

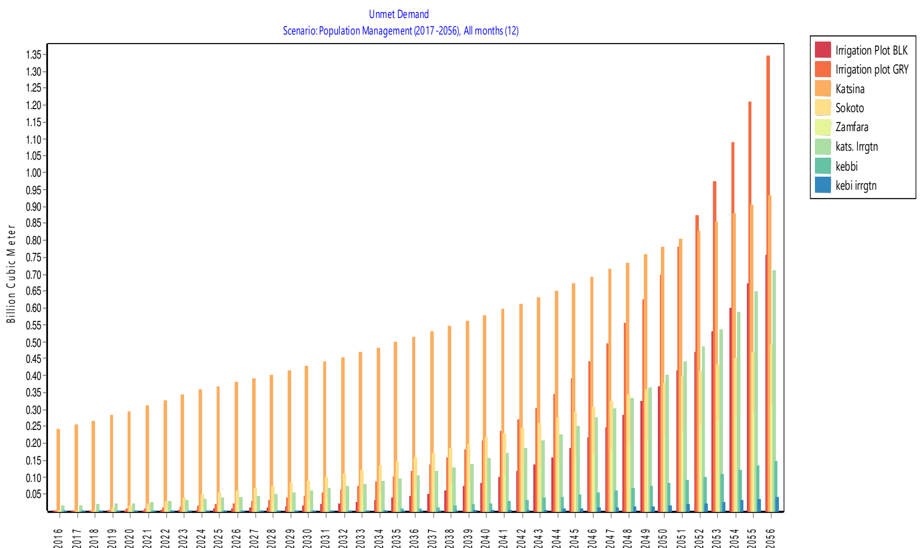

Figure 7: Unmet Demand for Population Management Scenario

Table 8: Supply delivered from all water sources in the basin in ($10^6 m^3$) 2017-2024.

	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
Irrigation Plot BLK	20.8	22.9	25.2	27.7	30.3	32.7	35.3	38.1	40.9	273.8
Irrigation plot GRY	34.0	37.2	39.9	42.4	45.0	47.5	50.4	53.6	56.9	407.0
Katsina	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sokoto	102.2	113.5	122.5	130.8	138.5	145.6	153.1	160.9	168.5	1,235.4
Zamfara	91.4	95.0	100.8	106.9	112.7	117.1	121.5	126.1	130.3	1,001.9
kats. Irrgtn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kebbi	90.8	96.2	102.0	108.0	114.3	120.9	127.8	135.0	142.5	1,037.3
kebi irrgtn	2.5	2.8	3.0	3.3	3.7	4.0	4.4	4.9	5.4	34.0
Sum	341.7	367.5	393.4	419.1	444.5	467.8	492.4	518.5	544.6	3,989.4

Source: Author's computation 2022

in Bakolori rose from 20.8 $x10^6$ m^3 in 2016 to 44.6 x $10^6 m^3$ in 2024, Goronyo irrigation also had increase in water demand from 34.0 $x10^6$ m^3 in 2016 to 72.6 x $10^6 m^3$ in 2024, katsina irrigation has a jump from 15.7 x $10^6 m^3$ to 33 x $10^6 m^3$as well as the kebbi irrigation which has a projection water demand of 5.4 x $10^6 m^3$ in 2024 from a value of 2, 5 $x10^6 m^3$ in 2016. Municipal water demand including industrial, commercial, and domestic activities for the sub basins of Sokoto, Kebbi, Katsina and Zamfara had the following respectively, 102.2 to 215.8, 90.8 – 142.5, 242.8 – 358.2 and 91.4 – 142.0x $10^6 m^3$. From the Table 8, the yearly supply delivered to the demand sites are as presented, it could be seen that the volume of water delivered to the demand sites also increases yearly

Table 9: Unmet demand to the demand sites in $10^6 m^3$ (2017 – 2024).

	2016	2017	2018	2019	2020	2021	2022	2023	2024	Sum
Irrigation Plot BLK	0.0	0.0	0.0	0.0	0.2	0.8	1.6	2.5	3.7	8.7
Irrigation plot GRY	0.0	0.2	1.3	2.8	4.8	7.2	9.8	12.7	15.9	54.7
Katsina	242.8	255.2	268.1	281.7	295.7	310.4	325.7	341.6	358.2	2,679.5
Sokoto	0.0	0.5	3.9	8.7	14.8	22.2	29.9	38.1	47.3	165.5
Zamfara	0.0	0.0	0.0	0.0	0.6	2.9	5.5	8.2	11.7	28.9
kats. Irrgtn	15.7	17.3	19.0	21.0	23.0	25.4	27.9	30.7	33.7	213.8
Kebbi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
kebi irrgtn	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sum	258.5	273.2	292.4	314.2	339.1	368.9	400.5	433.8	470.5	3,151.1

Source: Author's computation 2022

Table 10: Unmet Water demand Simulated for population growth (2017 – 2056) $10^9 m^3$.

	Irrgtn	BLK	Irrgtn	GRY	Katn	Sokoto	Zamfara	kats. Irrg	kebbi	kebi irrgtn	Sum
2016	0.0		0.0		0.2	0.0	0.0	0.0	0.0	0.0	0.3
2017	0.0		0.0		0.3	0.0	0.0	0.0	0.0	0.0	0.3
2018	0.0		0.0		0.3	0.0	0.0	0.0	0.0	0.0	0.3
2019	0.0		0.0		0.3	0.0	0.0	0.0	0.0	0.0	0.3
2020	0.0		0.0		0.3	0.0	0.0	0.0	0.0	0.0	0.3
2021	0.0		0.0		0.3	0.0	0.0	0.0	0.0	0.0	0.4
2022		0.0		0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.4
2023		0.0		0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.4
2024		0.0		0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.5
2025		0.0		0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.5
2026		0.0		0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.5
2027		0.0		0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.6
2028		0.0		0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.6
2029		0.0		0.0	0.4	0.1	0.0	0.1	0.0	0.0	0.6
2030		0.0		0.0	0.4	0.1	0.0	0.1	0.0	0.0	0.7
2031		0.0		0.1	0.4	0.1	0.0	0.1	0.0	0.0	0.7
2032		0.0		0.1	0.5	0.1	0.0	0.1	0.0	0.0	0.8
2033		0.0		0.1	0.5	0.1	0.0	0.1	0.0	0.0	0.8
2034		0.0		0.1	0.5	0.1	0.1	0.1	0.0	0.0	0.9
2035		0.0		0.1	0.5	0.1	0.1	0.1	0.0	0.0	0.9
2036		0.0		0.1	0.5	0.2	0.1	0.1	0.0	0.0	1.0
2037		0.1		0.1	0.5	0.2	0.1	0.1	0.0	0.0	1.1
2038		0.1		0.2	0.5	0.2	0.1	0.1	0.0	0.0	1.2
2039		0.1		0.2	0.6	0.2	0.1	0.1	0.0	0.0	1.3
2040		0.1		0.2	0.6	0.2	0.1	0.2	0.0	0.0	1.4
2041		0.1		0.2	0.6	0.2	0.1	0.2	0.0	0.0	1.5
2042		0.1		0.3	0.6	0.2	0.1	0.2	0.0	0.0	1.6
2043		0.1		0.3	0.6	0.3	0.1	0.2	0.0	0.0	1.7
2044		0.2		0.3	0.7	0.3	0.1	0.2	0.0	0.0	1.9
2045		0.2		0.4	0.7	0.3	0.2	0.2	0.0	0.0	2.0
2046		0.2		0.4	0.7	0.3	0.2	0.3	0.1	0.0	2.2
2047		0.2		0.5	0.7	0.3	0.2	0.3	0.1	0.0	2.3
2048		0.3		0.6	0.7	0.3	0.2	0.3	0.1	0.0	2.5
2049		0.3		0.6	0.8	0.4	0.2	0.4	0.1	0.0	2.7
2050		0.4		0.7	0.8	0.4	0.2	0.4	0.1	0.0	2.9
2051		0.4		0.8	0.8	0.4	0.2	0.4	0.1	0.0	3.2
2052		0.5		0.9	0.8	0.4	0.3	0.5	0.1	0.0	3.4
2053		0.5		1.0	0.9	0.4	0.3	0.5	0.1	0.0	3.7
2054		0.6		1.1	0.9	0.5	0.3	0.6	0.1	0.0	4.0
2055		0.7		1.2	0.9	0.5	0.3	0.6	0.1	0.0	4.4
2056		0.8		1.3	0.9	0.5	0.3	0.7	0.1	0.0	4.7
Sum		6.1		12.1	22.2	7.8	4.1	7.7	1.3	0.3	61.5

Source: Author's computation 2022

from 341.7 $x10^6 m^3$ in 2017 to a total of 544.6 x $10^6 m^3$ in 2024. This therefore leads to a high level of unmet demand in the whole basin ranging from the irrigation plots and the municipal water demand. Table 9 shows the unmet demand as computed by the WEAP model. In 2016 the total unmet demand stood at 258.5 $x10^6 m^3$ and it increases through the years to reaching 470.5 $x10^6 m^3$ in 2024. It was evident that unmet demand for irrigation at Bakolori programme started in 2020 with 0.2 x $10^6 m^3$ and rose gradually with time to a value of 3.7 x $10^6 m^3$ in 2024 (Table 10). Goronyo irrigation project started having unmet demand in 2017 with a value of 0.2 x $10^6 m^3$ which tends to grow through the years to a value of 15.9 $x10^6 m^3$ in 2024. Subsequently Katsina irrigation also suffered unmet demand since 2016 with a value of 15.7 $x10^6 m^3$ which grows through the years to 33.7 $10^6 m^3$ in 2024.

Future scenario results (population management)

For the impact of population management to be felt on

Table 11: Unmet Water Demand Simulated for low Population growth (2017 -2056) x10^{6}m^3.

	IrriBLK	IrrigG	Katsina	Sokoto	Zamfara	kats. Igtn	kebbi	kebi irgtn	Sum
2016	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2017	0.0	0.1	254.1	0.4	0.0	17.3	0.0	0.0	272.0
2018	0.0	1.2	265.9	3.6	0.0	19.0	0.0	0.0	289.7
2019	0.0	2.6	278.1	8.0	0.0	21.0	0.0	0.0	309.7
2020	0.1	4.5	290.7	13.6	0.6	23.0	0.0	0.0	332.5
2021	0.8	6.8	303.8	20.5	2.7	25.4	0.0	0.0	360.0
2022	1.5	9.4	317.4	27.6	5.3	27.9	0.0	0.0	389.2
2023	2.4	12.1	331.6	35.1	8.0	30.7	0.0	0.0	419.9
2024	3.5	15.1	346.2	43.0	11.2	33.7	0.0	0.0	452.8
2025	4.9	17.9	355.2	47.5	14.5	37.1	0.0	0.0	477.1
2026	6.3	21.3	364.4	52.6	17.7	40.8	0.0	0.0	503.1
2027	8.0	25.3	373.9	58.2	21.0	44.9	0.0	0.0	531.4
2028	10.0	30.1	383.6	64.6	24.3	49.4	0.0	0.0	562.0
2029	12.2	35.8	393.6	71.4	27.9	54.3	0.0	0.0	595.2
2030	14.7	42.1	403.8	78.4	31.5	59.8	0.0	0.0	630.3
2031	17.7	49.8	414.3	86.4	35.6	65.8	0.0	0.0	669.6
2032	21.3	58.4	425.1	94.5	40.1	72.3	0.0	0.0	711.7
2033	25.8	69.1	436.2	104.0	45.5	79.6	0.2	0.0	760.3
2034	30.9	81.1	447.5	113.7	51.2	87.5	0.8	0.1	812.7
2035	36.7	94.9	459.1	124.1	56.9	96.3	1.9	0.1	870.2
2036	43.2	111.0	471.1	135.2	62.8	105.9	3.5	0.3	933.0
2037	50.6	129.5	483.3	146.9	69.0	116.5	5.7	0.5	1,002.1
2038	59.4	150.1	495.9	158.7	75.8	128.1	8.5	0.8	1,077.2
2039	70.5	173.1	508.8	170.6	84.3	141.0	11.6	1.2	1,161.2
2040	82.9	198.8	522.0	182.5	93.0	155.1	14.8	1.7	1,250.6
2041	97.3	227.9	535.6	195.0	102.3	170.6	18.7	2.3	1,349.5
2042	115.1	260.2	549.5	207.4	113.4	187.6	22.9	3.0	1,459.1
2043	135.6	296.2	563.8	220.0	125.2	206.4	27.2	3.8	1,578.2
2044	158.4	336.0	578.4	232.5	137.1	227.0	31.5	4.7	1,705.8
2045	184.4	380.9	593.5	245.6	149.6	249.7	36.2	5.8	1,845.7
2046	213.2	430.5	608.9	258.7	162.1	274.7	40.8	7.0	1,995.9
2047	245.3	485.5	624.7	271.9	174.8	302.1	45.6	8.4	2,158.4
2048	280.9	546.3	641.0	285.0	187.6	332.4	50.5	9.9	2,333.5
2049	321.0	614.3	657.7	298.7	200.9	365.6	55.6	11.7	2,525.3
2050	365.3	689.3	674.8	312.2	214.2	402.2	61.2	13.7	2,732.9
2051	414.5	772.3	692.3	326.0	227.9	442.4	68.6	16.5	2,960.3
2052	468.8	863.8	710.3	339.7	241.5	486.6	76.0	19.6	3,206.4
2053	529.6	965.5	728.8	353.8	255.8	535.3	83.9	23.1	3,475.8
2054	596.6	1,077.6	747.7	368.0	270.0	588.8	91.9	27.1	3,767.7
2055	670.8	1,201.3	767.2	382.3	284.6	647.7	100.1	31.6	4,085.5
2056	752.6	1,337.6	787.1	396.6	299.2	712.5	109.6	37.0	4,432.2
Sum	6,053.1	11,825.3	20,029.6	6,534.6	3,925.0	7,679.6	967.4	229.8	57,244.3

Source: Author's computation 2022

the water allocation and its impact on unmet demand two conditions were simulated: these are (a) Decrease in population growth and (b) Increase in population growth rate within the basin. So, with the use of the stated factors as presented in (Table 10). Table 10 shows the impact of the present population growth on the unmet water demand in the basin from 2017 till 2056. Unmet demand on annual rates for irrigation plots in the basins, which are Bakolori irrigation projects, Goronyo irrigation projects, Kebbi/ Zauro poulda irrigation projects and katsina irrigation were all negligible in 10^{9}m^3 in 2017 and grew progressively to 0.8, 1.3, 0.7 and 0.1 x 10^{9}m^3 in the year 2056 (Figure 7). Also, the municipal subbasin water demand for population in the Sokoto Kebbi Zamfara and Katsina were negligible in the year 2017 except for Katsina with a value of 0.2 x10^{9}m^3 of water. However, there will be increment in the Unmet water demand to the tune of 0.5, 0.1,0.3 and 0.9 10^{9}m^3 for the Sokoto, Kebbi, Zamfara and Katsina Subbasins respectively. This shows that with the current water use and available water resources there will be lots of water needed to take care of unmet created by the year 2056 in the Sokoto- Rima River basin. The results of the second simulated situation under the Scenario "Population management" is presented as follows. In this scenario the population growth in each of the subbasins were changed based on the assumptions initially declared in (Table 11). where the percentage growth are; Sokoto, 2.5%, katsina, 2.6%, kebbi, 2.8% and Zamfara, 3.1%. The unmet demand has appreciably simulated and reduced for all the demand sites within the basin compared with what is obtained in the reference scenario. In 2017, the unmet were only observed at the katsina subbasin and it is 242 x10^6 m^3. However, the unmet demand increases for all the subbasins progressively to the year 2056 as simulated and presented in (Table 11, Figure 8) above and depicted by the chart that follows.

Demand sites inflow and out flows

At present the inflows into the demand sites have been studied and found to be irrational as the outflow

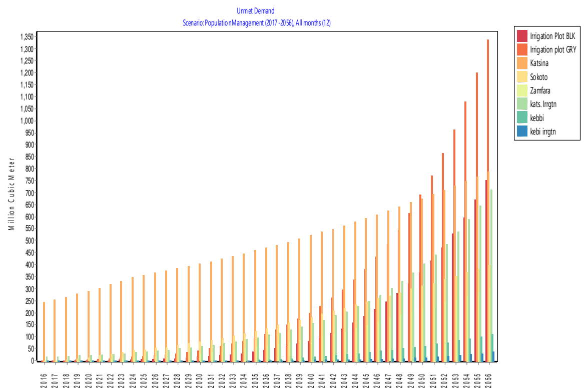

Figure 8: Unmet Water Demand for 2nd Population Management Scenario

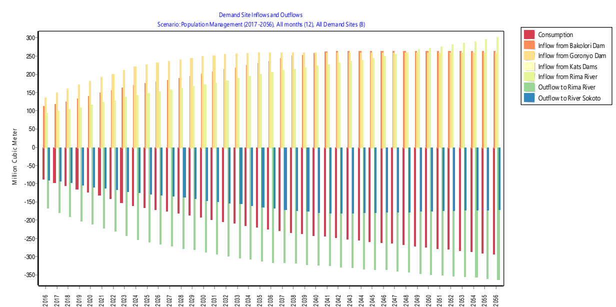

Figure 9: Demand Sites Inflows and Outflows

Table 12: Unmet Demand for The Water Demand Reduction Scenario in the Sub Basins and agriculture (2017-2056) x$10^6$$m^3$ (Monthly Average.).

	Irrig BLK	Irrig GRY	Kats	Sok	Zam	kats.Irrgtn	kebbi	kebi irrgtn	Sum
January	14.4	27.7	45.9	19.0	8.9	15.9	4.7	1.0	137.6
February	13.2	25.8	41.9	17.9	8.2	14.5	4.7	1.0	127.2
March	14.5	28.6	45.9	20.0	9.0	15.9	5.3	1.1	140.2
April	14.2	27.9	44.5	19.7	8.9	15.4	5.4	1.1	137.0
May	13.6	28.7	45.9	20.2	8.4	15.9	4.5	0.9	138.1
June	11.8	22.8	44.5	13.9	7.2	15.4	1.1	0.3	116.9
July	9.3	22.9	45.9	13.8	5.3	15.9	0.2	0.1	113.4
August	7.7	20.0	45.9	11.2	4.2	15.9	0.0	0.0	105.0
September	7.2	17.8	44.5	9.6	3.9	15.4	0.0	0.0	98.3
October	9.3	21.3	45.9	12.3	5.2	15.9	0.1	0.0	110.1
November	11.1	23.4	44.5	14.6	6.6	15.4	1.1	0.3	116.9
December	13.9	27.0	45.9	18.2	8.7	15.9	3.7	0.8	134.0
Sum	140.0	294.0	541.4	190.4	84.5	187.3	30.7	6.5	1,474.8

Source: Authors Computation 2022.

surpasses the water requirement of some of the demand sites which lead to excess drainage in the system. This assertion is represented in the chart as shown in (Figure 9).

Scenario 2 (Reduction in water demand and sourcing water from alternative sources)

For the objective of this work to be achieved, scenarios which seek water demand reduction for households in the subbasins, reduction in the irrigation water use as well as incorporation of alternative water supply in the entire basin has been created. The effect of the scenario is therefore simulated and its impact on unmet water demand in the entire basin is presented in (Table 12 and Figure 10).

Irrigation management scenario

Under this scenario a reduction in the amount of water allocated to irrigation has been proposed and simulated results show that both monthly averages and annual total

Table 13: Monthly Averages of Unmet demand for Irrigation Management Scenario 10^6m^3

	Irrigation Plot BLK	Irrigation plot GRY	Katsina	Sokoto	Zamfara	kats. Irrgtn	kebbi	kebi irrgtn	Sum
Jan	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
Feb	0.0	0.0	18.8	0.0	0.0	1.2	0.0	0.0	20.0
March	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
April	0.0	0.0	19.9	0.0	0.0	1.3	0.0	0.0	21.2
May	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
June	0.0	0.0	19.9	0.0	0.0	1.3	0.0	0.0	21.2
July	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
August	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
Sept.	0.0	0.0	19.9	0.0	0.0	1.3	0.0	0.0	21.2
October	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
Nov.	0.0	0.0	19.9	0.0	0.0	1.3	0.0	0.0	21.2
Dec.	0.0	0.0	20.6	0.0	0.0	1.3	0.0	0.0	21.9
Sum	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5

Source: Authors Computation 2022

Table 14: Annual total of unmet demand under the irrigation management scenario 10^6m^3.

	Irrigation Plot BLK	Irrigation plot GRY	Katsina	Sokoto	Zamfara	kats. Irrgtn	kebbi	kebi irrgtn	Sum
2016	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2017	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2018	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2019	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2020	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2023	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2024	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2025	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2026	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2027	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2028	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2029	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2030	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2031	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2032	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2033	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2034	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2035	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2036	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2037	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2038	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2039	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2040	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2041	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2042	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2043	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2044	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2045	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2046	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2047	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2048	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2049	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2050	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2051	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2052	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2053	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2054	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2055	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
2056	0.0	0.0	242.8	0.0	0.0	15.7	0.0	0.0	258.5
Sum	0.0	0.0	9,953.6	0.0	0.0	645.4	0.0	0.0	10,599.0

Source: Authors Computation 2022

of unmet demands were drastically reduced to zero in all the demand sites except for Katsina municipal and Katsina irrigation where there persisted unmet demand as depicted in the (Tables 13, 14 and Figure 11) as well

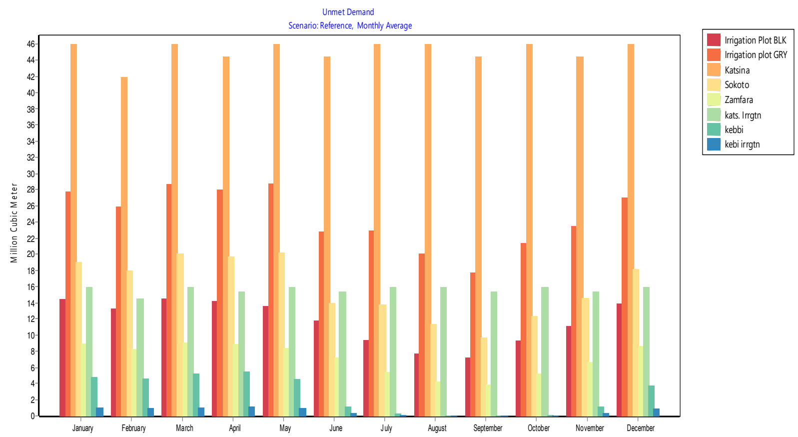

Figure 10: Monthly Average of unmet Demand for the scenario in which there is reduction of water demand from households in the subbasins as well as irrigation water reduction.

Figure 11: Chart showing Unmet demand for irrigation improvement Scenario results.

as the charts that follows.

Conclusion

Overall, the WEAP-model is an effective tool for optimizing water resource allocation. The basin's resources can meet site demands, given proper allocation methods. Municipal demands do not significantly impact the overall water needs of the basin. However, irrigation is the largest water consumer, with annual consumption rising. Unmet water demand is increasing, but solutions like population management and alternative sourcing may alleviate the issue. Improved irrigation practices can reduce unmet demand, except in the Katsina subbasin. With projected growth in irrigation, efforts should focus on maintaining low unmet water demand.

Recommendations

The following recommendations have been suggested for water allocation optimization within the Sokoto Rima River Basin as observed in the work.

1. Implementation of water assessment within the basin, to properly identify all water demand sites and appropriate their needs.
2. Water auditing should be carried out in the entire basin, with the assistance of water resources experts for proper allocation and ultimately optimization.
3. It is indeed important to review the irrigation farming methods/ procedures used in the whole basin and carry out reconstruction and re-orientation of the farmers on the importance of new methods of irrigation to save water.
4. Alternative water sources, apart from the dams and the river water needs to be identified and harnessed to bring about effective allocation of water to the demand sites.
5. Policymakers should be encouraged to involve the use of softwares such as WEAP in time-to-time study of the basins performance and for future planning of water allocation in the basin.

REFERENCES

Abdullahi S. A., Muhammad M. M., Adeogun B. K., I. U. Mohammed, (2014): *Assessment of Water Availability in the Sokoto Rima River Basin, Resources and Environment, Vol. 4 No. 5, 2014, pp. 220-233. doi: 10.5923/j.re.20140405.03.*

Ariel Dinar, Mark W. R., and Ruth M.(2015). Water allocation mechanisms principles and examples

Ekpoh I. J. , and Ekpenyong Nsa (FRGS) (2011): '*The Effects of Recent Climatic Variations on Water Yield in the Sokoto Region of Northern Nigeria"; International Journal of Business and Social Science Vol. 2 No. 7; [Special Issue –April 2011.*

Federal Republic of Nigeria (2004): National water policy

Netherlands Environmental Assessment Agency, 2005,

Robert S, Li Y, Tom L Q., Guy P. and Zhou Z. (2014): Basin Water Allocation Planning Principles, Procedures and Approaches for Basin Allocation Planning. UNESCO, Paris.

Robert S, Li Y., T. Le Quesne, G. Pegram and Z. Zhiwei (2013) Basin Water Allocation Planning. Principles, procedures and approaches for basin allocation planning, UNESCO, Paris

Savenije, H.H.G. and van der Zaag, P. (2000): *Conceptual framework for the management of shared river basins; with special reference to the SADC and EU. Water Policy, 2 (1), 9-45.*

UN-ESCAP (United Nations, Economic and Social Commission for Asia and the Pacific) (2000): *Principles and Practices of Water Allocation among Water-Use Sectors, ESCAP Water Resources Series Number 80, Bangkok, Thailand.*

Wang L. Z, Fang L. And Hipel K. W.(2003): Water Resources Allocation: A cooperative Game Theoretic Approach. *Journal of Environmental Informatics 2 (2) www.iseis.org/jei.htm*