Dams Utilization Analysis and Potentials to Enhance Irrigated Agriculture in Kano State, Nigeria

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Abstract

This paper explores the utilization level of the Tiga and Challawa Gorge dams and examineswhether these dams are been utilized effectively. The analysis employs a reservoir mass balance model to simulate dam operation using the monthly historical and hypothetical datasets for 10 years. The results revealed that the dams have been grossly underutilized with an average total historic annual yield of 1,800 Mm^3 and a spill of 1,554 Mm^3. When the releases were hypothetically increased without stressing the reservoir to failure, the average annual yield improved to 4,025 Mm^{3}and the spill reduced to 489 Mm^3. This produced a corresponding percentage increase in annual yield of 124% (2,225 Mm^3) and a percentage reduction in annual spills of 69%. The 30% of 2,225 Mm^3 (668 Mm^3) can be used for domestic water supply to 12 million people annually. Meanwhile, 70% (1,557 Mm^3) canbe used to irrigate an additional land of more than 95,000 Ha, which was estimated to generate economic returns of nearly 550 Billion Naira. This will immensely contribute to the economy of Kano State, thereby improving social well-being, food security and sustainable coexistence.

Keywords: Dam water utilization, Irrigated agriculture, Water supply, Kano State, Nigeria

1. Introduction

Kano State has the largest concentration of dams in Nigeria. The dams were constructed between the early 70thand mid-80th. However, these dams have been grossly underutilized for more than 5 decades, which may likely contribute to the frequent downstream floods as a result of high volumes of spills. Other problems that have been affecting these dams include sedimentation, weed infestation, and degradation of embankments, crests, spillways, and other infrastructures (Umma*et al.,* 2014). This paper focused on the two major dams in the State, the Tiga and Challawa Gorge dams. The Tiga Dam is the 5th largest Dam in Nigeria with a capacity of 1,986 Mm^3 whereas the Challawa Gorge Dam is the second largest in Kano State after Tiga Dam with a capacity of 996 Mm^3.

Issues related to underutilization of the dams water could exacerbate climate-induced problems like flooding events. Theseworriescould be accurately predicted and quantified if the dynamic of climate-informed flood-risk management tools were linked with human-induced problems (Shanono *et al.,* 2019). Such analysis serves as the problem-solving approach that embraces local understanding and global-local interactions as contained in the recently launched scientific decade (2023-2032) of the International Association of Hydrological Sciences (IAHS) aims at searching for sustainable solutions to unsought water-related circumstances (Arheimer *et al.,* 2024).Human (anthropogenic) activities have been one of the major downstream problems including. Dam Construction and operation thereby, obstructing the smooth flow of water. Humans alter the drainage systems by way of erecting structures either directly or indirectly on the waterways and other domestic activities that could amount to damage to drainage systems (Shanono *et al.,* 2022;

Shanono *et al.,* 2023). This study examine the level of Tiga and ChallawaGorge Dams utilization and analyze the potentials to enhance agriculture.

2.Materials and Methods

2.1 Study location

Figure 1 belowshows the map of the Kano and Jigawa States, the Tiga and Challawa Gorge dams and the Hadejia River Valley wetlands.

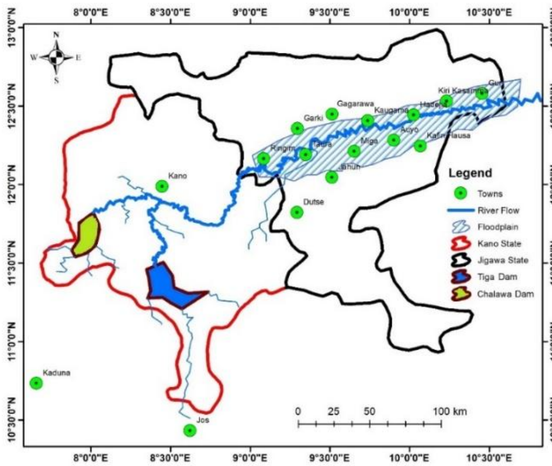

Figure 1: Hydrological Map of Hadejia River Valley showing Tiga and Challawa Gorge dams.

2.2 Reservoir simulation

Information on the operating rules of the Tiga and Challawa Gorge dams as well as other climatic, and hydrological datasets (rainfall, temperature, pan evaporation, inflow, releases, storage capacity) were obtained from the authorities of the Hadejia–Jama'are River Basin Development Authority (HJRBDA) and the Nigerian Meteorological Agency (NiMet). These datasets were used to assess and analyze the storage, spill, and release patterns for 10 seasons (2013/2014 to 2022/2023) monthly. The analysis was conducted using the reservoir simulation model (reservoir mass balance equation) as expressed in EqN.1. Three (3) variables of interest (storage levels, new reservoir capacity, and spillage if any) were computed at each simulation time step (monthly basis) based on the existing reservoir operating rules. The changes in reservoir surface area, and the area–capacity relationships for each reservoir were modelled and computed using the second-order polynomials, as found to fit better than the classic power-law model as expressed in Eqn. 2. Symon's pan evaporation was factored by 0.85 to obtain evaporation rates from the 2 reservoirs and used to compute the net evaporation losses from each reservoir as expressed in Eqn. 3. (Ndiritu, 2005).

$$S_{t+1} = S_t + Q_t - R_t - NE_t - SP_t \quad 1$$

$$0 \leq S_t \leq C_t$$

$$A_t = 0.2334S_t + 0.0023S_t^2 \quad 2$$

$$NE_t = \frac{1}{2}(A_t + A_{t+1})(0.85Ev_t - Pr_t) \quad 3$$

Where: S_t, and S_{t+1} = reservoir storage for time steps t and $t+1$. Q_t = natural inflow to the reservoir over time step t; R_t = water released from the reservoir for time step t. NE_t and SP_t = net evaporation losses and spills out of the reservoir over time. C_t = capacity of the reservoir for time t. NE_t, Ev_t and Pr_t are the net evaporation losses, average Symon's evaporation rate, and point rainfall respectively. A_t and A_{t+1} are the surface area of the reservoir in time t and $t+1$ respectively.

2.3 Reservoir Storage-Spills-Yield Analysis

The reservoir storage-spills-yield analysis was conducted and the aim was to evaluate the possible implications/effects of the Tiga and Challawa Gorge dams on the persistent and prolonged downstream floods along the Hadejia River Valley.The spills for each time step were sum-up for the entire simulation period (10 years) for both historical and hypothetical data as expressed in equations 4 and 5 respectively. The real data is the data collected from the reservoir operators while the hypothetical is the attempt to increase releases (yield) from the dams without stressing the dams to failure. In addition, the yield (release) for each time step was sum-up for the entire simulation period (10 years) for both historical and hypothetical data as expressed in Eqn. 6 and 7 respectively.

$$SPILLS_{Historical} = \sum_{t=0}^{n} SP_{t-his} \quad 4$$

$$SPILLS_{Hypothetical} = \sum_{t=0}^{n} SP_{t-hyp} \quad 5$$

$$YIELD_{Historical} = \sum_{t=0}^{n} R_{t-his} \quad 6$$

$$YIELD_{Hypothetical} = \sum_{t=0}^{n} R_{t-hyp} \quad 7$$

2.4 Analysis of the Hypothetically Released for Optimum Utilization

The difference between the historical and hypothetical annual yield was obtained by subtracting the earlier from the latter. The total number of people to be supplied with domestic water with 30% of the hypothetically released water was computed using the medium size households as suggested by Aminiet *al.,* (2022) and expressed in Eqn. 8. In addition, the potential irrigable land to be irrigated with 70% of the hypothetically released water for irrigation uses was also computed using the maximum crop water requirement of 1625 mm/Ha (0.01625 Mm^3/Ha) in semi-arid regions like Kano and Jigawa States with surface irrigation method (Ohwo and Abotutu, 2014) as expressed in Eqn. 9.

$$Number\ of\ People\ to\ be\ Supplied = \frac{30\%\ of\ YIELD_{Hypothetical}}{Amount\ of\ Water\ Required\ per\ Capita} \quad 8$$

$$Potential\ Irrigable\ Land = \frac{70\%\ of\ YIELD_{Hypothetical}}{Crop\ Water\ Required\ per\ Hectar\ in\ Semi-arid} \quad 9$$

3.Results and Discussions

3.1 Reservoir Storage Trajectories

A 10-year-long trajectory of the historic and hypothetical storage state of the Hadejia River System (the Tiga and Challawa Gorge Dams) is shown in Figure 2. Similar to the annual storage states presented in Figure 2, ineffective and effective water utilization were visually noticed for the historic and hypothetical storage levels respectively. In addition, the reservoir storage state for the 10-year shows a high level of utilization in a hypothetical scenario with the lowest storage level of less than 500 Mm^3 except for the 2 water calendar years with nearly 650 Mm^3. However, the reservoir storage state for the 10-year shows a low level of utilization in the historic scenario with the lowest storage level of nearly 1,800 Mm^3. Unlike in the historic storage state, in the hypothetical storage state, the water levels remain within safe limits throughout the rainy season with short periods and low volumes of spills, which was considered to be an effective reservoir operation (Biswas and Hossain, 2022).

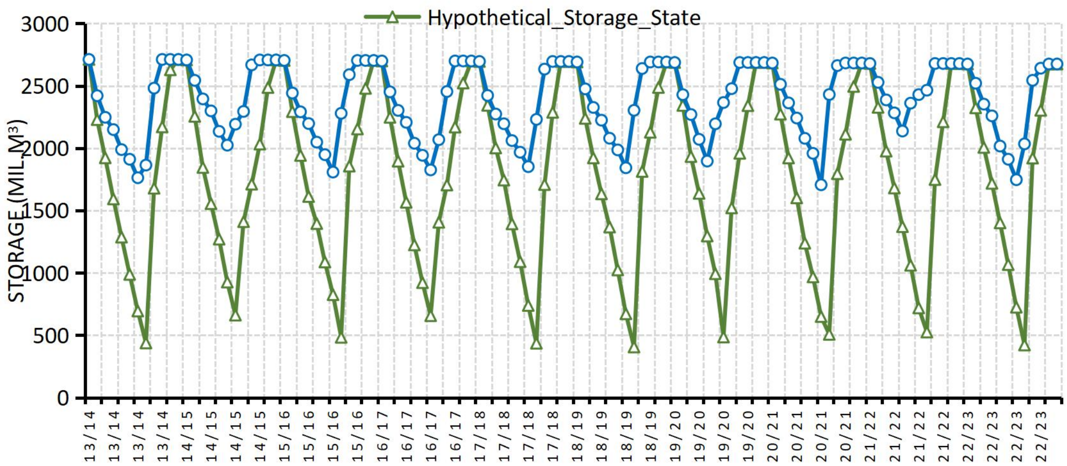

Figure 2: 10-year storage trajectory of Tiga and Challawa Dams

3.2 Historic and Hypothetical Yield

3.2.1 Yield analysis for the simulation period

A yield is the total amount of water successfully released to various water demand sectors. Figure 3 shows the historic and hypothetical yield obtained from the Tiga and Callawa Gorge Dams. The total 10-year historic yield of 18,001 Mm³ was obtained. However, for the hypothetical scenario, a significantly increased yield of 40,254 Mm³ was recorded. This indicated a substantial improvement in the reservoir performance with a yield increase of 124%. The increased yield also implies a greater ability to meet specified water demands with higher reliability which is crucial for water-stressed regions like semi-arid northern Nigeria known to persistently face erratic rainfall and other climatic conditions (Umar *et al.,* 2017). Having achieved such a higher yield, the hypothetical scenario proves to provide more reliable water releases, reducing the risk of shortages during dry periods or droughts and hence low volume of spills and short duration downstream floods (Padiyedath*et al.,* 2021; Shanono and Ndiritu, 2023). Identifying such a potential of releasing more water with a 124% increase is essential for supporting agricultural, industrial, and domestic water needs.

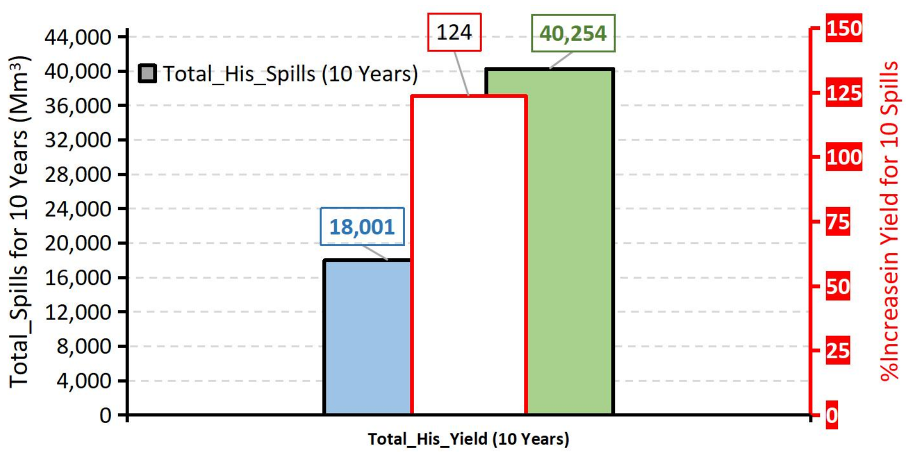

Figure 3: Historical and hypothetical yield obtained from both Tiga and Challawa Dam

3.2.2 Utilization of hypothetically released water

The difference between the historical and hypothetical annual yield of 2,225 Mm^3 was found, which can be used for domestic supply and irrigate purposes. Table 1 shows the proposed distribution of hypothetically released water (2,225 Mm^3) into 30% and 70% for domestic and irrigation uses which is equivalent to 667.5 and 1557.5 Mm^3 respectively. The people to be supplied with 30% of the hypothetically released water for domestic uses were computed to be 12,191,776 people in medium size households as suggested by Amini*et al.,* (2022). However, the potential irrigable land to be irrigated with 70% of the hypothetically released water for irrigation uses was computed to be 95,846 Ha using the maximum crop water requirement of 1625 mm/Ha (0.01625 Mm^3/Ha) in semi-arid regions like Kano and Jigawa States with surface irrigation method (Ohwo and Abotutu, 2014). It can be deduced that the hypothetical scenario has reduced spills by nearly two-thirds annually which can significantly reduce the possibility of prolonged downstream floods. Thus, to reduce floods in the HRV, there is a need to optimally utilize the Tiga and Challawa Gorge Dams through the development of more irrigation land and water supply to the City of Kano and the surrounding semi-urban towns (Shanono *et al.,* 2023).

Table 1: Distribution of hypothetically released water for domestic and irrigation uses

Hypothetically Released Water(Mm^3)	**30% of Unutilized Water for Domestic Supply**		**70% of Unutilized Water for Irrigation Supply**	
	(Mm^3)	***People to be Supplied (Number)***	***(Mm^3)***	***Land to be Supplied (Ha)***
2,225.00	667.50	12,191,776	1,557.50	95,846

3.2.3 Economic gain potentials from the hypothetically released water

Table 2 shows the revenue that could potentially be generated from 70% of the hypothetically released water (1,557.50 Mm^3) for irrigation purposes. Seven (7) major crops (rice, wheat, maize, beans, tomato, onion and pepper) were hypothetically assumed to be grown in the 95,846 Ha, which was computed as the irrigable land that can be irrigated with the 70% of the hypothetically released water from both Tiga and Challawa dams. This analysis gathers important information, such as the percentage of land allotted to each crop, the overall predicted yield, the potential cultivated land area, average yearly yield per hectare and dry season financial returns based on 2024 market values as summarized in Table 2. Other information generated from the literature includes the average yield of each crop per Ha, appropriate bags/baskets per Ha during dry season.

The projected yield from these seven crops when irrigated with 70% of the hypothetically released water is expected to generate a staggering ₦549,402,760,166.97 every dry season farming. This revenue reflects the potential economic impact from effective irrigation practices through optimum utilization the water from the Tiga and Challawa Dams. This analysis generated insights on the potentials of huge financial benefits that could be realized through effective dam water utilization.

Table 2: Revenue potentials from the 70% of the hypothetically utilized water for irrigation purposes

S/N	Crops	% of Land Cultivated per Crop	Potential Land to be Cultivated from 95,846 Ha/Crop	Average Annual Yield (Tons/Ha)	Average Annual Yield (Bags/Ha or Baskets/Ha)	Total Estimated Yield (Bags or Baskets)	Cost of Crop/Bags or Basket as of 2024 (Naira)	Total Annual of Crop (Naira)
1	Rice	38.76	37,149.61	4.50	69.23	2,571,896.24	60,000.00	154,313,774,597.50
2	Wheat	8.53	8,172.91	2.00	30.77	251,474.30	100,000.00	25,147,429,934.41
3	Maize	17.05	16,345.83	4.60	70.77	1,156,781.78	80,000.00	92,542,542,158.62
4	Beans	3.88	3,714.96	4.00	61.54	228,613.00	95,000.00	21,718,234,943.35
5	Tomato	15.50	14,859.84	95.00	1,461.54	21,718,234.94	4,500.00	97,732,057,245.08
6	Onion	4.65	4,457.95	20.00	307.69	1,371,678.00	70,000.00	96,017,459,749.55
7	Pepper	11.63	11,144.88	9.03	138.92	1,548,281.54	40,000.00	61,931,261,538.46
		100.00	**95,846.00**					**549,402,760,166.97**

4. Conclusion

This study analyzed the utilization level of the Tiga and Challawa Gorge dams and assess if these dams are been utilized effectively. The analysis employs a reservoir mass balance equation to simulate dam operation using the monthly historical and hypothetical datasets for 10 years. The results revealed that the dams have been grossly underutilized with an average total historic annual yield of 1,800 Mm^3 and a spill of 1,554 Mm^3. When the release was hypothetically increased without allowing the reservoir to fail, the average annual yield increased to 4,025 Mm^3 and the spill reduced to 489 Mm^3. This produced a corresponding percentage increase in annual yield of 124% (2,225 Mm^3) and a percentage reduction in annual spills of 69%. The 30% of 2,225 Mm^3 (668 Mm^3) can be used for domestic water supply to 12 million people annually. Meanwhile, 70% (1,557 Mm^3) can be used to irrigate an additional land of more than 95,000 Ha, which was estimated to generate economic returns of nearly 550 Billion Naira. This will immensely contribute to the economy of Kano State, thereby improving social well-being, food security and sustainable coexistence.It can be inferred that the hypothetical scenario has revealed potentials for more social-economic well-being through reliable water supply and economic returns.

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