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An Analysis of Water Demand of the Rural Population within the Iishana System, Namibia

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ABSTRACT
The Namibian people, particularly, those living within the Iishana system, which is a subset of the Cuvelai Basin, often encounter recurrent floods and droughts. After each rainy season, the Iishana system dries up gradually, hence, water for both agriculture and potable purposes becomes crucial. With the anticipated new water infrastructural development and rehabilitation of existing ones, it will be necessary to ascertain the water demand of the rural population, for the quantification of the supply potential to improve water availability. This study adopts historical water consumption per capita recommended within the Iishana system to determine the rural population demand. Considering a thirty years' population projection, the water demand of the Iishana system is properly estimated. Moreover, the historical hydrological dataset daily data for the period 2012-2021 was used for the analysis. The current demand is estimated at 2,479 cubic meters per day. The projections of water demand for the rural population for 2033, 2043, and 2053 are 0.9, 0.5, and 0.1 Mm^3/year, respectively. More so, the surface water resource potential of the system is estimated at an average of 300 mm/year. The region loses more water through evaporation than it receives in the wet season. Around 2500 mm of water evaporates from the surface annually, giving a water deficit of 2200 mm/year. The region's flat, shallow landscape, high evaporation rate, and the inadequacy of infrastructure have made the area vulnerable in terms of water security for both agricultural and potable purposes, resulting in droughts after the rainy season. With these findings, it is recommended to build water infrastructures within the region to improve the well-being and livelihood of rural communities.

Keywords: Water demand, Water supply, Rural population, Per capita demand, Iishana system, Namibia

INTRODUCTION

Water is a finite and vulnerable resource, vital to sustain life, development, and the environment, and should be recognized as an economic good, according to the Dublin principles (Mays, 2011). Water has evolved into a highly intricate commodity as it has been subjected to the principle of supply and demand. While planning a water supply scheme, water demand is assessed, to know the quantity of water required for an area (Basak, 2003).

The challenges associated with a water supply and its management have become a vital concern. Due to increased population growth, complimented by climate change, the water demand has increased, putting more pressure on the limited available water resources. Water shortage, access to clean water, and sanitation have meant that water planners must balance finite water resources among domestic, agricultural, and ecosystem uses (United Nations-Water, 2018). To attain this, the full integration of water supplies, water quality, and environmental considerations must be necessitated (World Bank, 2022).

The estimation of water demand is very complex and intense. (MAWF, 2014) stated the various mathematical models that are, however, utilized for predicting future water demand. These include extrapolating historical trends, using simulation modelling, or correlating demand with socio-economic factors. These methods differ in complexity based on the number of criteria considered and how extensively water users are broken down by sectors, geographical location, season, or other variables (MAWF, 2014).

With anticipated new water infrastructural development and rehabilitation of existing ones, it is necessary to ascertain the water demand of the rural population within the Iishana system, to quantify the supply potential to increase water availability. This study focuses on giving the balance between water demand and supply in terms of surplus/deficit to per capita demand.

MATERIALS AND METHODS

Study area

The study area shown in Figure 1 is located within southern Angola and north-central parts of Namibia. It has a coverage area of 18,370 km^2 (47.4% in Angola and 52.6% in Namibia). The rural area covers 9,516 km^2 and has a total current rural population of 61,969. The region is complex, where water availability depends on annual rainfall, temperature, and recurrent flooding, which replenish the shallow ephemeral river streams, locally known as Iishana (plural) or Oshana (singular), and recharge groundwater (Mendelsohn & Weber, 2011).

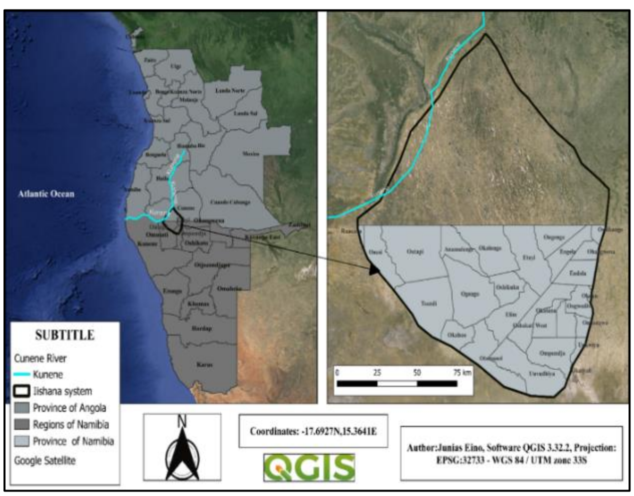

Figure 1. The study area of the Iishana system

Procedures for forecasting population

To compute the available population 3 previous decades' populations were considered. The population record is obtained from the official census records. Governments usually conduct these official surveys, known as censuses, every 10 years. To evaluate the total population numbers of the study area, the first step is to calculate the population for each region. Figure 2 shows the regional zones of the Iishana system. The second step is to use the population density for each region to calculate the population in each area, and then the totals are summed to get the overall population numbers. The rural population in 2023 and the preceding three decades is calculated by subtracting the urban population from the total population numbers (refer to Table 1). Figure 3 depicts the towns within the Iishana system.

The future population for the next 3 decades was consequently calculated based on the rural population in 2023 and the past 3 decades. To predict probable future populations different methods are available. While none of these methods are entirely precise and are all founded on probability laws, they can provide only approximate projections for future populations. The selection of a particular methodology for a given area relies heavily on the factors that are considered within such approaches. The decision ultimately rests on the designer's discretion and acumen. The Arithmetical Increase Method, Geometrical Increase Method, Incremental Increase Method, and Decreasing Rate of Growth Method were considered in this study and are explained in detail below (Basak, 2003).

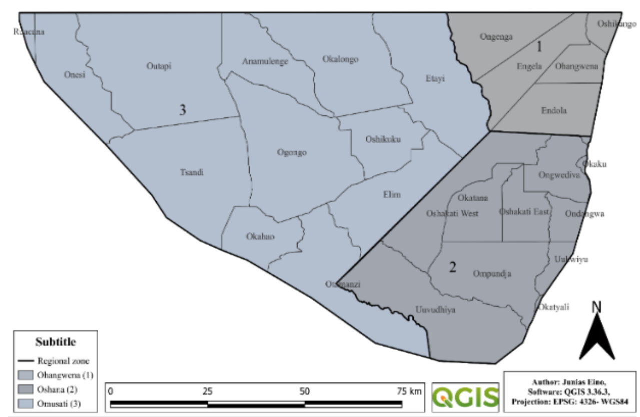

Figure 2. Regional zones of the Iishana system

Table 1. Urban population within the Iishana system (Census, 1991, 2011, 2023)

Urban	Area (ha)	2023	2011	2001	1991
Okahao	599	4,519	1,665	*	*
Oshikuku	792	5,499	2,761	*	*
Outapi	2,768	13,671	6,437	2640	*
Tsandi	703	2,595	*	*	*
Ongwediva	4,182	27,784	20,260	10,742	6,197
Oshakati	5,630	58,696	36,541	28,255	21,603
Total	14,675	112,764	67,664	41,637	27,800

* These areas are not yet proclaimed as urban.

Arithmetical increase method

In this method, it is assumed that the population increases at a constant rate. The average population increase is calculated based on the records from past decades. This average is then added to the present population and the population of successive decades to obtain the projected population. The population predicted by this method is the lowest among all forecasting methods. The forecasted population (P_n) after 'n' decades from the last known census can be calculated using the following (Eq. 1):

$$P_n = P_0 + n\bar{x} \tag{1}$$

Where: P_0 is the population at the last known census, $\bar{x}$ is the arithmetic mean of population increase in the known decades, and n is the number of decades between the last census and the future.

Geometrical increase method

In this method, it is assumed that the percentage increase in population remains constant. The percentage increase is calculated from available census records. Subsequently, the population of future decades is estimated using this percentage increase. This method yields the highest predicted population of all. The forecasted population (P_n) after 'n' decades is given by (Eq.2):

$$P_n = P_0\left(1 + \frac{r}{100}\right)^n \tag{2}$$

Where: P_0 is the population at the last known census, r is the probable rate of population increase per year (%)

Incremental increase method

In this method, the average population increase is calculated using the arithmetic increase method. Then, the average incremental increase is calculated. Finally, both averages are combined to project the population in future decades. The population predicted by this method falls between the predictions of the arithmetic increase method and the geometrical increase method. The population after "n" decades from the last known census is given by (Eq.3):

$$P_n = P_0 + l_a + nl_c \tag{3}$$

Where: P_0 is the population at the last known census, l_a is the average Arithmetical increase, l_c is the average Incremental increase.

Decreasing rate of growth method

The growth of life is limited. At times, growth starts off fast and then slows down. To calculate this, the average decrease in percentage increase is determined and subtracted from the percentage increase of each following decade. This average is then used to predict the population of the following decades (Eq. 4).

$$P_n = P_0 + \left(\frac{r - r_1}{100}\right) \times P_0 \tag{4}$$

Where: P_0 is the population at the last known census, r is the population increase for the last census (%), r_1 is the decrease in the percentage increase in population.

Procedures for calculating water demand

Water demand for domestic use

Water demand for domestic is the water consumed in residential houses for drinking, cooking, bathing, sanitation, and gardening, and depends mainly on living conditions (Mays, 2011). Using the adopted historical water consumption per capita of 40l/c/d for the Iishana system (MAWF, 2014), the domestic water demand is determined, successfully. The theoretical demand for water was calculated by multiplying the projected rural population by the individual domestic consumption.

Water demand for livestock

Livestock demand is water required for livestock drinking and depends on the age, stock size, and climatic conditions (Mays, 2011). On average, Large Stock Unit (LSU), including cattle, donkeys, or horses, consume about 45 liters/stock unit/day (MAWF, 2014). The livestock demand was computed by multiplying the livestock figure with the appropriate water consumption. Livestock numbers for the study area are calculated based on the carrying capacity of the rural areas at 10 ha/LSU (MAWF, 2014).

Water provision procedures

Water provision was determined based on the historical hydrological dataset daily data for the period 2012-2021, obtained from (SASSCAL WeatherNet). The study considered the Okalongo, Mahenene, Omafo, and Ogongo weather stations within the Iishana system, as depicted in Figure 3.

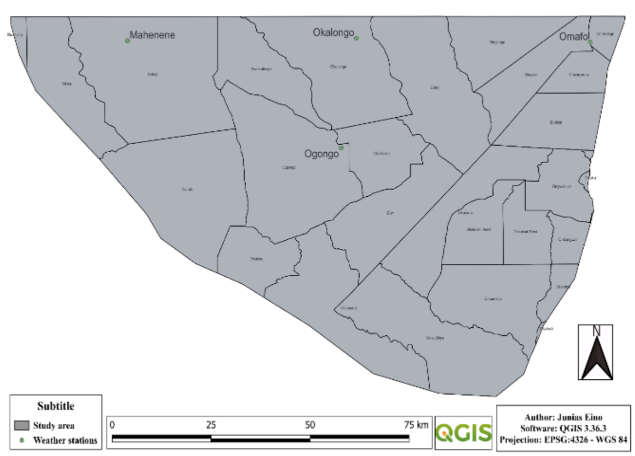

Figure 3. Weather stations within the Iishana system

RESULTS AND DISCUSSION

Population forecasting and justification of the adopted method

The probable future population is estimated using different methods highlighted in section 2.2. Theoretical results obtained from each of these methods are then compared with the actual population in 2023. Figure 4 shows the comparison of the actual and estimated population by various approaches for the Iishana system. The Arithmetic Increase Method (A.I.M) gives higher results than the actual one. The Geometric Increase Method (G.I.M) and the Incremental Increase Method (I.I.M) gave almost the same results, and the results are higher than the actual one. The Decreasing Rate of growth Method (D.R.M) exceeded the actual population slightly. This method gave satisfactory results compared to the other three methods. Hence, the Decreasing Rate of growth Method is used to estimate the probable future population.

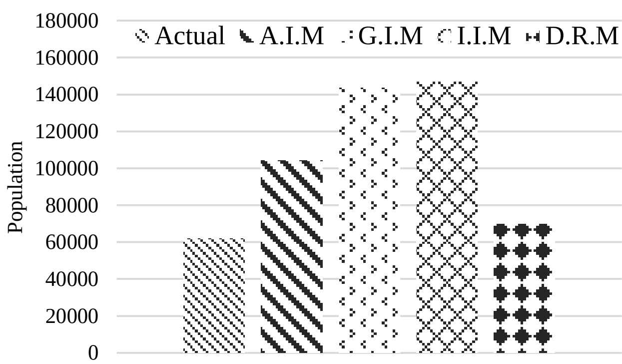

Figure 4. Comparison of actual and estimated population for the Iishana system

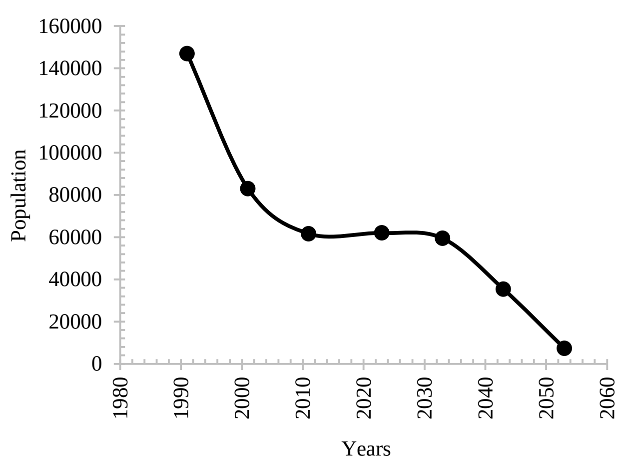

Figure 5. Estimation of the probable future population for the Iishana system.

Figure 4 shows the estimation of the probable future population for the Iishana system using the Decreasing Rate of growth Method. A declining population has been predicted furtherance to previous trend based on census data. A significant declining population difference of 84,970 has been observed between 1991 and 2023 (Table 1).

Current rural water demand estimation

The estimated water demand for the present year 2023/24 was calculated based on the current domestic population and livestock numbers, using adopted water consumption norms. The resulting estimate of the current rural water demand is shown in Table 3.

The total current rural water demand was calculated at 6,761 m^3/d, with the domestic demand at 2,479 m^3/d and the livestock demand at 4,282 m^3/d, being 37% and 63% of the total, respectively (Figure 6).

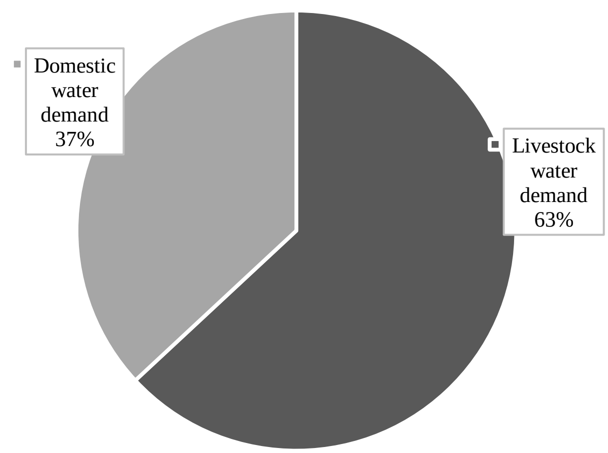

Figure 6. The water demand for various purposes within the Iishana system

Projected future rural water demand of the Iishana system

The anticipated future demand for water in the rural areas were estimated based on the projected future rural population. However, livestock numbers are not considered because they depend on the grazing capacity of the rangeland, which is not expected to improve over time. Figure 7 displays the estimated water demand for the rural population for the Iishana system. The water demand projections for 2033, 2043, and 2053 are 0.9, 0.5, and 0.1 Mm^3/year, respectively. The decrease in water demand is a result of a population decline (Figure 5), as people move from rural to urban migration for better economic and social opportunities (Census, 2011). The urban population increased by 75%, while the rural population decreased by 58% over a thirty-two (32) year period, from 1991 to 2023 (Table 2). The well-being and livelihood of rural communities are greatly affected by several challenges such as poor maintenance of water infrastructure, long distances to communal taps, inability to pay for municipal water supply, limited capacity to carry water, and specific times allocated for collecting water (Arendt *et al.*, 2021; Niipare, 2020; Shooya, 2017).

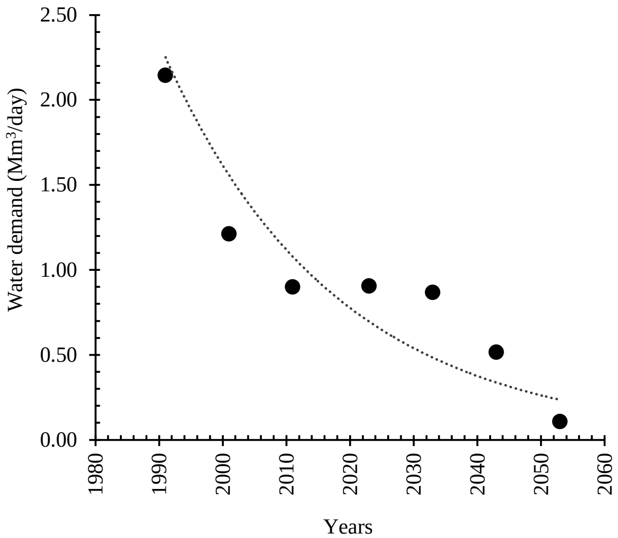

Figure 7. Estimated water demand for the rural population for the Iishana system.

Water provision

To estimate the supply potential for the Iishana system, the daily weather data were obtained from four key stations: Okalongo, Mahenene, Omafo, and Ogongo. However, it is found that both Omafo and Okalongo stations have limited data records from 2019 to 2021, with several missing data records. The Mahenene station has hydrological data from 2012 to 2019 but also with missing data records. On the other hand, the Ogongo station has satisfactory daily data records, making it the most reliable station out of the three. With hydrological data sets covering 2012 to 2021, the data from the Ogongo station is used to estimate precipitation, temperature, and evaporation rates for the Iishana system. The evaporation rate (E_r) is calculated using the energy balance method (Han, 2010) as follows (4):

$$E_r = \frac{1}{l_v \rho_w}(R_n - H_s - G) \quad (4)$$

Where: E_r is evaporation rate (m/s), H_s is sensible heat flux (in W/m^2, to change liquid water temperature), G is the ground heat flux (in W/m^2, to change underlying soil temperature), R_n is the net radiation flux (W/m^2), ρ_w is water specific density (kg/m^3), l_v is the latent heat of vapourization (J/kg), calculated using (5).

$$l_v = 2.5 \times 10^6 - 2370T \quad (5)$$

Where T is temperature in ^{0}C.

Precipitation

The Figure 8 depicts the total yearly precipitation for the Iishana system, recorded at Ogongo station. The results display that the annual average precipitation in the Iishana system is about 300mm. The lowest recorded precipitation was below average in 2018 (marking the beginning of 2019 drought), while the highest precipitation of 600mm was recorded in 2020. The rainwater received flows down to the Etosha pan by gravity, resulting in a shortage of water within the region (Dragnich *et al.*, 2007).

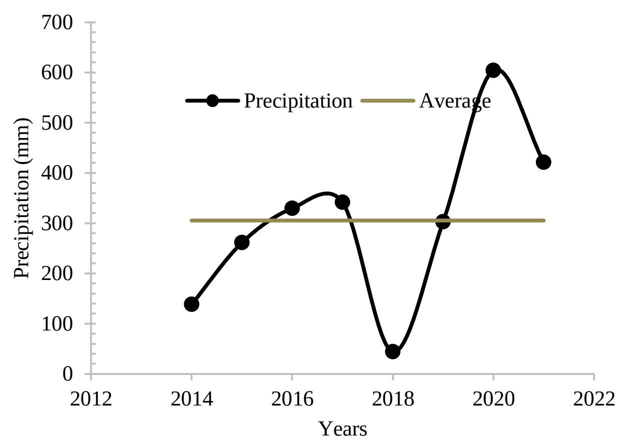

Figure 8. Total yearly precipitation for the Iishana system (2014-2021), recorded at Ogongo station.

Temperature

Figure 9 and Figure ***10*** show the temperature pattern for the Iishana system, recorded at Ogongo station. It is visible that the temperature series followed a positive trend in both figures. The water that remains in the Iishana (stream) and surface water bodies evaporates because of a high temperature. The computed annual evaporation rate is 2500 millimeters (using (4) and (5)). With an average of 300mm of rainfall annually (Figure 8), the amount of water evaporating is eight (8) times more than the amount of rainfall (Figure 11).

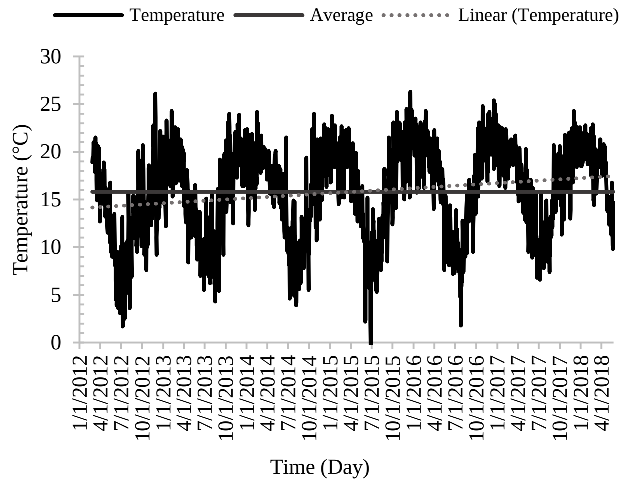

Figure 9. Daily temperature for the Iishana system (2012-2018), recorded at Ogongo station.

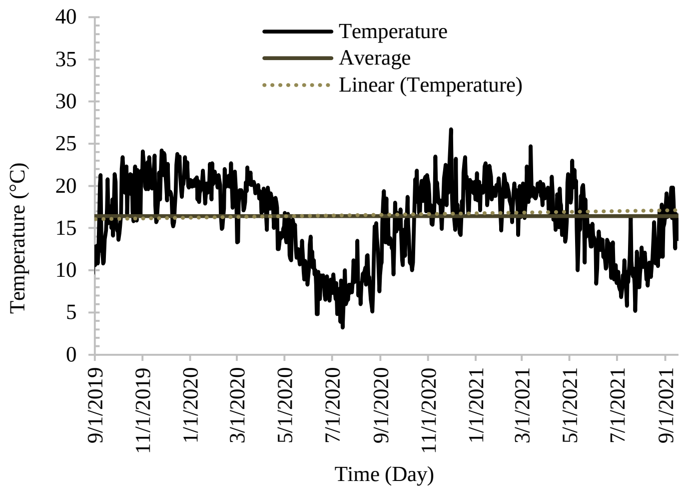

Figure 10. Daily temperature for the Iishana system (2019-2021), recorded at Ogongo station.

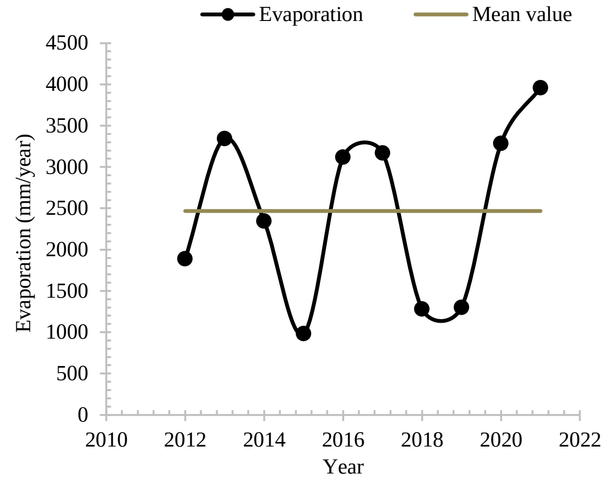

Figure 11. Evaporation within the Iishana system

Table 2. The population within the Iishana system from 1991 to 2023 (Census, 1991, 2011, 2023)

Year	Region	Area km^2	Population Density per km^2 Person/ km^2	Population Per region [No]	Population [Total No]	Urban Population [Total]	Rural Population [Total]
[1]	[2]	[3]	[4]	[5]	[6]*	[7]	[8]
	Ohangwena	1,136	32	36,352			
2023	Oshana	2,411	27	65,097	174,733	112,764	61,969
	Omusati	6,107	12	73,284			
	Ohangwena	1,136	23	26,128			
2011	Oshana	2,411	20	48,220	129,311	67,664	61,647
	Omusati	6,107	9	54,963			
	Ohangwena	1,136	21	23,856			
2001	Oshana	2,411	19	45,809	124,628	41,637	82,991
	Omusati	6,107	9	54,963			
	Ohangwena	1,136	18	20,448			
1991	Oshana	2,411	26	62,686	174,739	27,800	146,939
	Omusati	6,107	15	91,605			

*Total population numbers for the 3 regions in the respective year.

Table 3. Estimated current (2023/24) water demand of the Iishana system

Domestic			Livestock				Total Rural Water Demand
Rural Population	**Water Consumption Per capita**	**Demand**	**Area**	**Livestock Numbers***	**Water Consumption per stock**	**Demand**	
[Total]	**[m^3/capita/d]**	**[m^3/d]**	**[ha]**	**[Total]**	**[m^3/capita/d]**	**[m^3/d]**	**[m^3/d]**
61,969	0.04	2,479	951,587	95,156	0.045	4,282	6,761

*Equivalent large stock units

CONCLUSION AND RECOMMENDATION

This study analyzed the water demand of the rural population within the Namibian Iishana system. The current water demand of the rural population is estimated at 2,479 m^3/d, with projections of 0.9, 0.5, and 0.1 Mm^3/year for 2033, 2043, and 2053 respectively. The region's flat, shallow landscape, high evaporation rate, and lack of proper infrastructure have made the area vulnerable in terms of water security for both agricultural and potable purposes, resulting in droughts after the rainy season.

With these findings, it is recommended to build water infrastructures within the region to improve the well-being and livelihood of rural communities. One engineering practice involves increasing the storage capacity of the natural basins in the study area by removing the accumulated sediment to retain sufficient water to increase water availability. Additionally, increasing the depth of the pans may help reduce the rate of evaporation. Furthermore, planting of trees within the basin will enhance ecological restoration, reduce flooding and enhance rural livelihoods' ability to withstand the impacts of climate change.

DECLARATIONS

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

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Authors' contribution

First Author analysed the data obtained and wrote the manuscript. Second and third Author supervised and revised the manuscript.

Competing interests

The authors declare no competing interests in this research and publication.

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