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Assessing the Current and Future Water Demand for Sustainable Reservoir Management in Muko Reservoir-Songwe, Tanzania

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ABSTRACT

Reliable projection of water demand is fundamental to sustainable reservoir planning in semi-arid regions, where population growth, climate variability and competing sectoral uses increasingly constrain water availability. In small reservoirs of sub-Saharan Africa, however, planning commonly proceeds without a systematic assessment of future demand, which risks over-allocation and reduced reservoir reliability. This study assessed current and projected water demand in the Muko Reservoir catchment, Songwe Region, Tanzania, over a 50-year planning horizon (2025–2075). It extends earlier work on reservoir evaporation losses towards a more complete water-balance assessment. Domestic, livestock, irrigation, industrial and environmental requirements were estimated using population projection techniques, livestock inventory analysis, standard water consumption rates and sectoral demand assessments. Combined domestic and livestock demand is projected to rise from 130.75 to 423.83 m^3 day^{-1}, an increase exceeding 220%. Under an integrated scenario incorporating irrigation and industrial development, total demand increases from approximately 140.8 to 808.0 m^3 day^{-1}. Irrigation emerges as the dominant sector (44.6%), followed by domestic supply (40.8%). The findings indicate that demographic growth, agricultural expansion and socio-economic development will be the principal drivers of future demand. Coupling projected demand with evaporation losses also yields a more realistic appraisal of reservoir performance. Reservoir management should therefore adopt adaptive operating rules, demand-management measures and climate-resilient allocation strategies, supported by periodic updating of demand projections. The proposed framework is transferable to small reservoirs across semi-arid Tanzania and sub-Saharan Africa.

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1.0 Introduction

Reservoirs are critical components of water-resource systems in semi-arid and climate-vulnerable regions, providing strategic storage for domestic water supply, livestock production, irrigation, environmental flows, and drought resilience. In many parts of sub-Saharan Africa, including Tanzania, increasing population growth, urbanisation, agricultural expansion, and climate variability are intensifying pressure on limited water resources, making accurate estimation of water demand a prerequisite for sustainable reservoir planning and operation (URT, 2022). While considerable attention has traditionally been given to hydrological inflows and storage capacity during reservoir design, the long-term viability of water infrastructure depends equally on understanding current and future water demands within the service area.

The challenge of balancing water supply and demand is particularly pronounced in semi-arid environments where rainfall is highly seasonal and hydrological systems exhibit substantial interannual variability. Under such conditions, reservoirs function not merely as storage structures but as instruments for managing hydrological risk and ensuring water security. Consequently, reservoir planning requires a comprehensive assessment of both the available water resources and the magnitude, timing, and evolution of water demand across multiple sectors (Loucks & van Beek, 2017). Failure to adequately quantify future water requirements can result in under-designed infrastructure, unreliable water supply systems, and increased vulnerability to drought conditions.

In Tanzania, water demand is increasing rapidly due to demographic and socio-economic transformations. The National Water Policy emphasises integrated water resources management (IWRM) approaches that account for competing water uses while ensuring equitable and sustainable allocation among stakeholders (URT, 2002). Recent studies have highlighted that many rural and semi-urban communities remain vulnerable to water shortages due to growing demand and limited storage infrastructure (Kashaigili *et al.,* 2021). As a result, robust water-demand forecasting has become an essential component of reservoir feasibility studies, operational planning, and long-term water-security assessments. Recent comparative efforts have shown that forecasting performance varies considerably between methods, emphasising the necessity of careful model selection and uncertainty treatment (Alvisi *et al.,* 2025).

The Muko Reservoir, located in the Songwe Region of southwestern Tanzania, is a typical example of a small but strategically important water-storage system designed to support domestic and livestock water supplies in a semi-arid environment. The reservoir catchment experiences a unimodal rainfall regime, seasonal water stress, and increasing land-use pressures that collectively influence water availability and demand. Recent research by Waled *et al.* (2026) developed a multi-model framework for estimating evaporation losses from the Muko Reservoir and demonstrated that annual atmospheric water losses constitute a significant component of the reservoir water balance. Their study indicated that potential evapotranspiration in the catchment exceeds 1,500 mm per year and highlighted the importance of incorporating evaporation estimates into reservoir operation and water-resource planning. Furthermore, the authors concluded that improved water budgeting is essential for enhancing reservoir reliability and supporting climate-resilient water management in the region.

While the study by Waled *et al.* (2026) substantially improved the understanding of evaporation dynamics in the Muko Reservoir, a comprehensive assessment of water demand remains lacking. Reservoir sustainability depends not only on quantifying water losses through evaporation but also on accurately estimating the volume of water required by present and future users. Water-demand assessment, therefore, represents the logical next step in developing a complete reservoir water-balance framework. Integrating demand estimates with evaporation losses enables the assessment of reservoir yield, storage adequacy, supply reliability, and vulnerability to future climatic and demographic changes.

Previous studies have demonstrated that population growth, changes in consumption

patterns, livestock expansion, and economic development significantly influence water demand in rural and peri-urban communities (Maidment, 1993; Loucks & van Beek, 2017). In developing countries, water-demand forecasting is increasingly employed to support infrastructure investment decisions, reservoir operation policies, and climate-adaptation strategies. Demand assessments typically incorporate demographic projections, sectoral water-use requirements, and planning horizons to estimate future resource needs under various development scenarios. Such approaches are particularly valuable in semi-arid regions where water availability is constrained, and competition among users is expected to intensify.

Against this background, the present study aims to assess current and future water demand within the Muko Reservoir service area and evaluate its implications for sustainable reservoir management. Specifically, the study seeks to (i) (i) (i) (i) quantify existing water demand for domestic, livestock, and other relevant uses; (ii) project future demand under population growth and development scenarios; and (iii) provide a scientific basis for integrating demand estimates with previously quantified evaporation losses to support reservoir operation, planning, and water-security assessments. By linking water-demand analysis with the evaporation assessment framework developed by Waled *et al.* (2026), this study contributes toward a comprehensive understanding of the Muko Reservoir water balance and provides evidence-based guidance for climate-resilient water-resource management in the Songwe Region of Tanzania.

1.1 Description of the Study Area

The Muko Dam catchment occupies a geographically and hydrologically significant position in Mengo Village, Ndalambo Ward, within Momba District of the Songwe Region in southwestern Tanzania. Situated between latitudes 8°37′S–8°39′S and longitudes 31°31′E–31°33′E, the dam site is established at coordinates 36:445211.3E, 8999944.8N at an elevation of 1,555.75 metres above sea level—a setting that places it squarely within the transitional upland zone of the East African Rift periphery, where physiographic complexity intersects with acute livelihood vulnerability (Figure 1). The dam itself is a small earth-fill structure constructed under the auspices of the United Republic of Tanzania's Ministry of Water (URT–MoW, 2022), with a design life of 50 years, a gross storage capacity of 166,386.5 m^3, an embankment extending 250 metres in length and rising 9.1 metres in height, and discharge regulated through an unlined trapezoidal spillway. Its primary mandate is the provision of domestic and livestock water to a population estimated at over 11,671 people and 3,430 animals across the surrounding villages of Mengo, Ndalambo, Kakozi, and Nakawale — communities whose dependence on this single infrastructure is total, given the near-complete absence of perennial surface water and the severely constrained groundwater endowment of the sub-region (TRDP, 2020; URT–NBS, 2022).

The catchment encompasses approximately 14.39 km^2 of moderately dissected terrain, characterised by steep hillslopes and narrow valley floors with gradient profiles ranging from 3 to 15%. Land cover is heterogeneous, comprising grasslands, rain-fed croplands, bushland, and seasonal wetlands, a mosaic that reflects both ecological variability and the cumulative impact of human activity. Of particular analytical concern is the condition of the upper catchment, where sustained overgrazing and agricultural encroachment have caused widespread land-surface degradation, accelerated erosion dynamics and substantially increased sediment loading within the drainage network (URT–MoA, 2023; Nyembo &Msuya, 2022). These processes constitute a well-documented feedback loop in smallholder agrarian systems across sub-Saharan Africa, in which subsistence pressure on marginal lands progressively undermines the very hydraulic infrastructure on which rural populations depend.

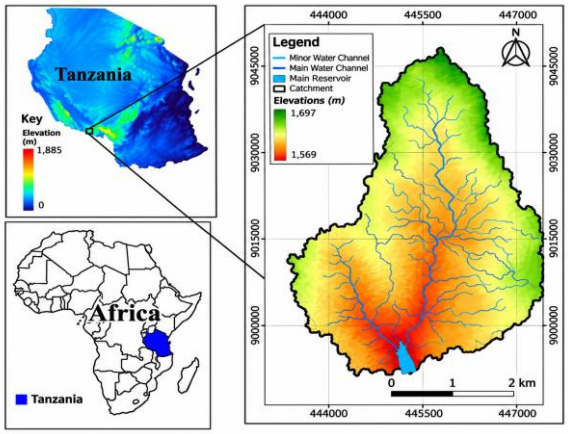
Climatically, the catchment is governed by a semi-arid tropical highland regime exhibiting a unimodal precipitation pattern concentrated in the November-to-April wet season, with mean annual rainfall ranging between 800 and 1,100 mm. Thermal conditions are comparatively mild, with temperatures oscillating between 16°C and 29°C; however, the climatic water balance is fundamentally deficient, as potential

evapotranspiration consistently exceeds 1,500 mm per annum — a structural imbalance that generates pronounced seasonal water stress and renders inter-annual variability in rainfall particularly consequential for reservoir storage and community water security (TMA, 2022; Msuya & Mwita, 2021). Hydrologically, the catchment operates under an ephemeral flow regime in which surface runoff generation is confined to the rainy months, reflecting the shallow infiltration capacity of degraded upland soils and the rapid drainage response of a predominantly crystalline basement geology. The underlying hydrogeological framework is characteristic of much of Tanzania's interior: Precambrian crystalline basement rocks of low primary porosity and permeability dominate the subsurface, such that economically exploitable groundwater is largely restricted to weathered regolith horizons and discrete fracture networks (Davies & Ó Dochartaigh, 2002; Yohana *et al.,* 2023). This geological inheritance yields groundwater potential that is both spatially variable and systematically modest relative to sedimentary aquifer contexts, effectively foreclosing groundwater as a viable alternative supply and elevating the strategic irreplaceability of Muko Dam within the local water economy.

Taken together, these biophysical conditions – the constrained water balance, ephemeral hydrology, degraded catchment condition, and structurally limited groundwater endowment – configure a setting of pronounced hydraulic fragility. The dam thus operates not merely as a piece of rural infrastructure but as a critical node in a socio-ecological system under compound stress, where the consequences of sedimentation, watershed degradation, and climatic variability converge, with direct and immediate effects on human well-being. This vulnerability echoes broader patterns observed across small dam systems in the region, where the absence of robust watershed governance frameworks has consistently undermined the longevity of infrastructure and service delivery capacity (Nyembo & Msuya, 2022; Nkonya *et al.,* 2021; Tessema *et al.,* 2024).

Figure 1

Location of the Study Area (Waled et al., 2026)



2.0 Materials and Methods

This study adopts an integrated water-demand assessment framework to support sustainable reservoir planning and operation in the Muko Reservoir catchment (Figure 2). The framework is developed as a direct extension of the evaporation assessment undertaken by Waled *et al.* (2026), which quantified reservoir water losses using a multi-model evaporation estimation approach and demonstrated the importance of evaporation in the overall reservoir water balance. While that study addressed the atmospheric-loss component of the system, the present research focuses on the human-demand component, thereby providing the missing element required for a comprehensive evaluation of reservoir sustainability and water-security performance.

The conceptual foundation of the framework rests on the recognition that reservoir reliability is determined by the dynamic interaction between water availability and demand. Contemporary water-resource studies increasingly emphasise that effective reservoir management requires the simultaneous consideration of hydrological processes, climate variability, demographic growth, and sectoral water requirements rather than treating supply and demand as independent components (Ciampittiello *et al.,* 2024). Furthermore, recent reviews on water-demand forecasting highlight that population growth, socio-economic development, changing consumption patterns, and climate change are among the most significant drivers influencing

future water demand, particularly in water-stressed regions (Fang *et al.,* 2024).

The framework consists of four interrelated stages. The first stage involves assessing baseline water-demand conditions by collecting and analysing demographic, socio-economic, and water-use data from the reservoir's service area. This stage quantifies current domestic, livestock, institutional, and other sectoral water demands using established water-consumption standards and local water-use characteristics. Understanding existing demand conditions provides the foundation for evaluating future water requirements and identifying key demand drivers. The second stage focuses on future demand forecasting through population projection and development scenario analysis. Population growth is widely recognised as one of the primary determinants of long-term water demand and is routinely incorporated into reservoir planning and water-supply design (Fang *et al.,* 2024). Accordingly, demographic projections are used to estimate future service populations over the reservoir planning horizon, and these projections are translated into sector-specific water requirements in accordance with accepted planning standards. Multiple growth scenarios are considered to capture uncertainties associated with future demographic and socio-economic changes. This is consistent with the finding that no single forecasting approach is universally superior and that forecast uncertainty should be explicitly acknowledged (Alvisi *et al.,* 2025).

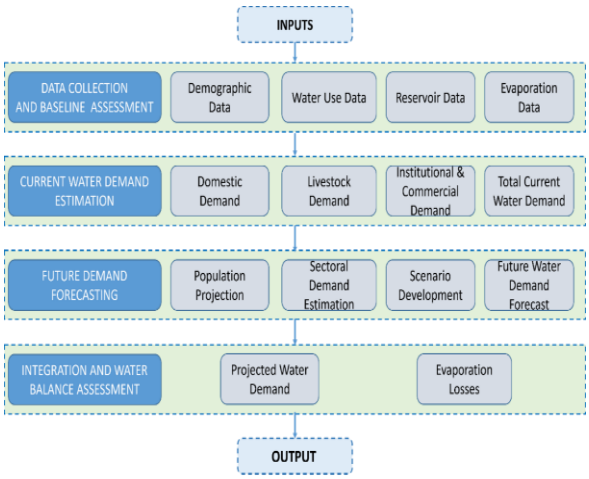
The third stage involves developing water-demand scenarios that represent different trajectories of population growth, economic development, and water-use behaviour. Scenario-based analysis has become an essential tool in water resource planning because it enables decision-makers to evaluate system performance under uncertain future conditions and assess the robustness of

management strategies (Ciampittiello *et al.,* 2024). By examining alternative demand pathways, the study identifies potential future pressures on reservoir resources and supports adaptive planning approaches.

The final stage integrates projected water demand with previously estimated reservoir evaporation losses to establish a comprehensive water-balance assessment framework. This integration is particularly important in semi-arid environments such as the Muko catchment, where evaporation constitutes a substantial component of total water losses and can significantly affect reservoir yield and supply reliability (Waled *et al.,* 2026). The combined analysis enables evaluation of the total reservoir water requirement, accounting for both consumptive withdrawals and climatic losses. Such integrated assessments are increasingly recommended as best practices within Integrated Water Resources Management frameworks because they provide a more realistic representation of system behaviour under changing climatic and socio-economic conditions (Ciampittiello *et al.,* 2024).

By linking demand forecasting with evaporation assessment, the framework provides a robust scientific basis for evaluating reservoir adequacy, estimating future water deficits, and supporting evidence-based decision-making. The approach further contributes to climate-resilient reservoir management by enabling the assessment of long-term water-security risks associated with population growth, changing demand patterns, and increasing hydroclimatic variability. Consequently, the framework serves not only as an analytical tool for the Muko Reservoir but also as a transferable methodology for water-demand assessment and reservoir planning in other semi-arid catchments across Tanzania and sub-Saharan Africa.

Figure 2
Flow Diagram of the Methodology for Water Demand Assessment for Muko Reservoir



3.0 Results and Discussion

3.1 Domestic Water Demand

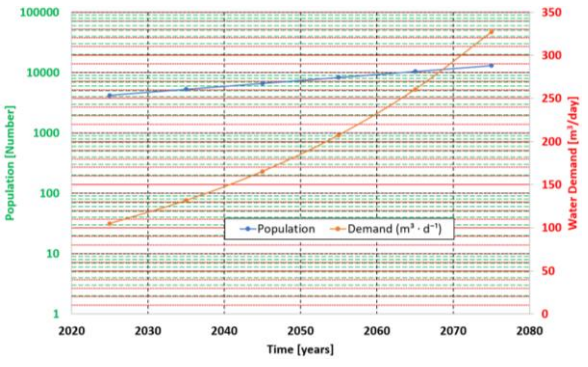
Figure 3 illustrates the projected temporal changes in population and the corresponding daily water demand over the planning horizon from 2025 to 2075. The figure demonstrates a continuous increase in both population and water demand, although the rates of increase differ markedly. While population growth follows a relatively moderate, near-linear trajectory, water demand exhibits a progressively accelerating trend, indicating that future water requirements are expected to increase faster than population growth alone. The population projection (left y-axis) indicates a steady increase from approximately 4,000 inhabitants in 2025 to more than 12,000 by 2075, representing approximately a threefold increase over the 50-year planning period. This growth reflects the long-term demographic expansion anticipated within the study area and is consistent with population projection methodologies commonly employed in municipal water supply planning (United Nations, 2022). Population growth remains one of the principal drivers of increasing water demand because larger populations require greater volumes of water for domestic, commercial, institutional, and public uses.

In contrast, the projected daily water demand (right y-axis) increases from approximately 100 m^3 day^{-1} in 2025 to nearly 330 m^3 day^{-1} by 2075. The non-linear (convex) nature of the demand curve suggests that water demand grows faster than the population, implying that future increases are influenced not only by demographic growth but also by rising per capita water consumption, improved service coverage, higher living standards, urbanisation, and socio-economic development. Similar trends have been widely reported in studies forecasting water demand, which demonstrate that economic development and improvements in water accessibility often led to disproportionately higher water consumption relative to population growth alone (House-Peters & Chang, 2011; UNESCO, 2024). The divergence between the two curves becomes increasingly evident after approximately 2055, when the slope of the demand for water steepens considerably relative to that of the population curve. This indicates that the existing water supply infrastructure may face increasing pressure as future demand outpaces demographic growth. If water production capacity, storage facilities, and distribution infrastructure are not expanded to meet projected demand, significant supply deficits may arise in the latter stages of the planning horizon.

From a water resources management perspective, the projections emphasise the need to adopt proactive planning strategies that can accommodate future increases in demand. Infrastructure expansion should therefore consider not only projected population growth but also anticipated changes in per capita water consumption, economic development, and service level improvements. This finding supports the principles of Integrated Water Resources Management (IWRM), which advocate long-term, adaptive planning to ensure sustainable and equitable allocation of limited water resources among competing sectors (Global Water Partnership, 2000). Overall, Figure 3 highlights the increasing disparity between population growth and water demand over time. Although the population is projected to increase steadily throughout the planning period, total water demand rises more rapidly, emphasising the necessity of incorporating both demographic and socio-economic drivers into long-term water demand forecasting models. These projections provide valuable information for the design of future water supply systems, enabling planners to determine appropriate capacities for water abstraction, treatment, storage, and distribution infrastructure while ensuring resilience against future demand uncertainty.

Figure 3

The Projected Water Demand and Population



3.2 Livestock Water Demand Projections

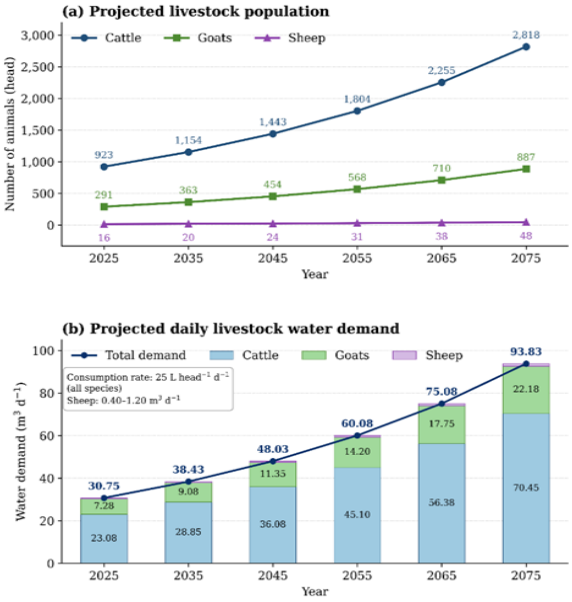
Figure 4 illustrates the projected growth in livestock populations and the corresponding daily water demand between 2025 and 2075. The projections indicate a steady and sustained increase in the populations of cattle, goats, and sheep throughout the planning horizon, resulting in a proportional increase in livestock water requirements. The analysis assumes a constant daily water consumption rate of 25 L $head^{-1}$ day^{-1} for all livestock categories, implying that changes in water demand are driven entirely by projected livestock population growth. The upper panel of Figure 4 shows that cattle remain the dominant livestock species throughout the projection period, increasing from 923 heads in 2025 to 2,818 heads by 2075, representing an overall increase of approximately 205%. Goat numbers exhibit a similar growth trajectory, rising from 291 to 887 head, while sheep populations increase more modestly from 16 to 48 head. The projected trends suggest sustained expansion of the livestock sector, likely reflecting anticipated population growth, increased agricultural production, improved animal husbandry practices, and rising demand for livestock products. Similar long-term increases in livestock populations have been reported in developing countries, where expanding human populations and economic growth continue to drive demand for animal protein and associated agricultural production systems (FAO, 2023).

The lower panel presents the projected daily water demand attributable to each livestock category together with the total livestock water demand. Cattle account for the largest share of total water demand throughout the projection period due to their substantially larger population. Daily cattle water demand increases from 23.08 m^3 day^{-1} in 2025 to 70.45 m^3 day^{-1} by 2075, while goat demand rises from 7.28 to 22.18 m^3 day^{-1} over the same period. Sheep contribute only a small proportion of total demand, increasing from 0.40 to 1.20 m^3 day^{-1}. Consequently, the total projected livestock water demand increases steadily from 30.75 m^3 day^{-1} in 2025 to 93.83 m^3 day^{-1} in 2075, representing an increase of approximately 205%. The nearly linear increase in total water demand reflects the assumption of constant per-animal water consumption. This proportional relationship is consistent with livestock water demand theory, whereby total water requirements are primarily determined by herd size when climatic conditions, production systems, and water intake rates remain unchanged (Mekonnen & Hoekstra, 2012). Although the present projections assume a fixed consumption rate of 25 L $head^{-1}$ day^{-1}, actual livestock water requirements may vary according to ambient temperature, physiological status, feed composition, breed characteristics, and production intensity. Under warmer climatic conditions, particularly in semi-arid environments, drinking water requirements may increase substantially because of elevated evaporative losses and heat stress (NRC, 2000).

From a perspective on water resource planning, the projected tripling of livestock water demand has important implications for future water supply infrastructure. Existing livestock watering facilities, reservoirs, groundwater abstractions, and distribution systems may become increasingly inadequate if capacity expansion does not keep pace with livestock growth. These findings emphasise the necessity of integrating livestock population projections into long-term water resource planning to ensure sustainable water allocation while minimising competition among domestic, agricultural, industrial, and environmental water users. Such integrated planning approaches are widely recommended within the framework of Integrated Water Resources Management (IWRM), which promotes coordinated management of water resources across competing sectors to enhance long-term sustainability (Global Water Partnership, 2000). Overall, Figure 4 demonstrates that future livestock water demand is expected to increase substantially over the next five decades, with cattle accounting for more than 75% of total livestock water requirements throughout the projection period. The results suggest proactive investment in livestock water infrastructure, strategic water conservation measures, and climate-resilient water management policies to ensure reliable water availability for the expanding livestock sector while safeguarding other water-dependent socio-economic and ecological systems.

Figure 4

Project Livestock Population Growth and Corresponding Daily Livestock Water Demand from 2025 to 2075



3.3 Irrigation Water Demand

Irrigation water demand within the Muko Reservoir catchment is primarily driven by seasonal agricultural activities, which are dominated by smallholder cultivation of maize, rice, and a variety of horticultural crops. Agricultural production in the catchment is highly dependent on rainfall, yet the intermittent nature of the Muko River, which ceases to flow during the dry season, necessitates supplementary irrigation to sustain crop growth and maintain agricultural productivity. Consequently, the proposed reservoir is expected to play a critical role in providing reliable water supplies during periods of water scarcity.

Although irrigation requirements are substantially reduced during the rainy season owing to effective precipitation, supplemental irrigation remains necessary during critical crop growth stages, particularly during planting, flowering, and grain-filling, when water stress can significantly reduce crop yields. The magnitude and temporal distribution of irrigation demand are therefore expected to vary seasonally in response to climatic conditions, crop water requirements, and cropping patterns.

Despite the recognised importance of irrigation in the study area, a quantitative assessment of irrigation water demand was not undertaken as part of this study because of insufficient data on irrigated land area, crop calendars, cropping intensity, soil characteristics, and crop-specific water requirements. Consequently, irrigation demand was excluded from the overall water demand projections presented in this study. Future investigations should incorporate detailed agricultural surveys together with crop water requirement modelling, using established approaches such as the FAO CROPWAT model, to quantify present and future irrigation requirements and enable comprehensive water allocation planning (Allen *et al.,* 1998).

3.4 Industrial and Commercial Demand

Industrial and commercial water demand within the Muko Reservoir catchment is presently modest, reflecting the predominantly rural nature of the local economy. Existing economic activities consist mainly of agro-processing enterprises, grain milling facilities, and small-scale brick production, all of which require relatively small but continuous volumes of water for processing, cleaning, equipment operation, and ancillary services. Industrial water demand was estimated through field surveys of existing enterprises combined with published unit water consumption coefficients. Water consumption rates of 0.1 m^3 $tonne^{-1}$ day^{-1} were adopted for grain milling operations, while 0.5 m^3 m^{-3} day^{-1} was applied for brick production. Based on anticipated socio-economic development within the catchment, industrial and commercial activities are projected to expand gradually, resulting in an estimated 20% increase in industrial water demand over the 50-year planning horizon.

Although industrial demand accounts for a relatively small share of total projected water demand, its continuous nature requires a reliable, uninterrupted water supply. Given the Muko River's ephemeral nature, relying solely on natural river flows would be insufficient to sustain industrial operations during prolonged dry periods. Accordingly, the proposed reservoir is expected to provide a dependable year-round water supply through dedicated supply infrastructure. Establishing separate industrial distribution systems would further reduce the potential for contamination of domestic water supplies while enhancing operational efficiency

and ensuring compliance with public health and water quality standards.

3.5 Environmental Flow Requirements

Maintaining adequate environmental flows is fundamental to preserving the ecological integrity of the Muko River system and sustaining downstream aquatic ecosystems, riparian vegetation, and associated wetland habitats. Environmental flow allocations are particularly important in non-perennial river systems, where prolonged periods of zero flow can severely disrupt ecosystem functioning, diminish water quality, and threaten aquatic biodiversity. To safeguard ecological processes, an environmental flow allocation of 15% of the mean monthly flow was adopted using the Tennant Method (Tennant, 1976), a widely applied hydrological approach for establishing minimum instream flow requirements. During the dry season, when natural river flows cease entirely, controlled releases from the reservoir are proposed to maintain a minimum base flow of 0.2 $m^3 s^{-1}$. These releases are intended to sustain aquatic habitats, facilitate fish movement, preserve riparian vegetation, and maintain acceptable downstream water quality conditions.

The environmental flow assessment demonstrates that regulated reservoir releases will be essential to preventing ecological degradation associated with the prolonged cessation of dry-season flows. Failure to maintain minimum environmental flows would likely result in habitat fragmentation, deterioration of water quality, loss of aquatic biodiversity, and degradation of downstream wetlands. Consequently, environmental water requirements should be incorporated as a fundamental component of the reservoir's operating policy alongside domestic, livestock, industrial, and agricultural water allocations. Integrating environmental flow releases within reservoir operation rules is consistent with the principles of IWRM, which advocate balancing human water demands with the long-term protection of freshwater ecosystems (Global Water Partnership, 2000). Such an approach will enhance the ecological sustainability of the reservoir while ensuring compliance with national environmental legislation and internationally accepted best practices for sustainable water resources management.

3.6. Total Water Demand

Figures 5 and 6 present the projected total water demand for the Muko Reservoir catchment between 2025 and 2075 and the relative contribution of each demand sector to the overall water requirement. Collectively, the figures illustrate not only the magnitude of future water demand but also the changing importance of individual demand sectors over the reservoir planning horizon. Such integrated assessments are fundamental to reservoir design because they enable planners to evaluate the combined effects of demographic growth, socio-economic development, agricultural expansion, and environmental water requirements within a single water allocation framework (Fallah-Mehdipour *et al.,* 2020; Droppers *et al.,* 2020). As illustrated in Figure 5, total water demand is projected to increase continuously throughout the planning period, reflecting sustained population growth and increasing pressure on water resources. The quantified demand rises from approximately 140.8 $m^3 day^{-1}$ in 2025 to 808.0 $m^3 day^{-1}$ by 2075, representing an increase of nearly 474%, or approximately 5.7 times the current demand. The trend indicates that water demand increases progressively over time rather than linearly, suggesting that future demand will be influenced not only by population growth but also by expanding economic activity, improved water service coverage, and increased agricultural development. Similar trends have been observed in integrated water-demand studies, where socio-economic development contributes substantially to future water demand beyond demographic growth alone (Droppers *et al.,* 2020).

The sectoral breakdown shown in Figure 5 further demonstrates that domestic water demand remains a principal consumer throughout the projection period, increasing from 100.0 $m^3 day^{-1}$ in 2025 to approximately 330.0 $m^3 day^{-1}$ by 2075. Livestock water demand follows a similar but more gradual trajectory, increasing from 30.8 $m^3 day^{-1}$ to 93.8 $m^3 day^{-1}$, reflecting the projected expansion of cattle, goat, and sheep populations. Industrial and commercial demand remains comparatively small, increasing from approximately 10.0 $m^3 day^{-1}$ to 24.2 $m^3 day^{-1}$,

consistent with the relatively low level of industrialisation currently characterising the catchment. Nevertheless, even relatively modest industrial demand requires continuous and reliable water supply infrastructure, particularly during prolonged dry seasons when natural streamflow is absent. Although irrigation demand could not be quantified directly due to limited data on irrigated land area, cropping patterns, and crop water requirements, the indicative scenario shown in Figure 5 demonstrates its potential significance within the future water allocation framework. By 2075, irrigation demand is projected to reach approximately 360 m^3 day^{-1}, exceeding both domestic and livestock water requirements. This finding is consistent with global and regional studies showing that irrigation commonly accounts for between 60% and 80% of total freshwater withdrawals, particularly in agricultural catchments where food production constitutes the dominant economic activity (Allen *et al.,* 1998; Ashine, 2021). The results, therefore, suggest that future reservoir operation should explicitly incorporate irrigation demand once reliable agricultural datasets become available, since excluding irrigation would substantially underestimate long-term reservoir storage requirements.

The proportional contribution of each sector, presented in Figure 6, provides further insight into the structure of future water demand. By 2075, irrigation is projected to account for approximately 44.6% of total demand, followed closely by domestic water use at 40.8%. Livestock demand contributes approximately 11.6%, while industrial and commercial activities account for only 3.0% of the total water requirement. These proportions demonstrate that future water allocation within the Muko Reservoir catchment will be dominated by domestic consumption and agricultural production, with irrigation emerging as the largest individual water-use sector. Such sectoral distributions are typical of rural catchments in sub-Saharan Africa, where agricultural production remains the principal driver of freshwater demand (Ashine, 2021). Beyond consumptive uses, environmental flow requirements remain an essential operational component of total reservoir releases. Although environmental flows are not represented as a consumptive demand in Figures 5 and 6, maintaining a minimum ecological release equivalent to 15% of the mean monthly flow, together with a dry-season base flow of 0.2 m^3 s^{-1}, is fundamental for sustaining downstream aquatic ecosystems, riparian vegetation, and water quality. Contemporary reservoir management increasingly recognises environmental flow allocations as an integral component of sustainable water resources planning rather than a competing water use (Fallah-Mehdipour *et al.,* 2020; Droppers *et al.,* 2020).

Overall, the projections presented in Figures 5 and 6 demonstrate that water demand within the Muko Reservoir catchment will increase substantially over the next five decades, with domestic water supply and irrigation together accounting for more than 85% of the projected total demand by 2075. When these projected demands are considered alongside reservoir evaporation losses previously estimated by Waled *et al.* (2026), the results highlight the need for an integrated reservoir management strategy that balances consumptive water use, environmental flow requirements, and climatic losses. Such integrated approaches are widely recognised as the foundation of sustainable water resource management and are consistent with the principles of Integrated Water Resources Management (IWRM), which advocate coordinated planning across all water-use sectors to ensure long-term water security while safeguarding ecosystem integrity (Global Water Partnership, 2000).

Figure 5
Total Water Demand

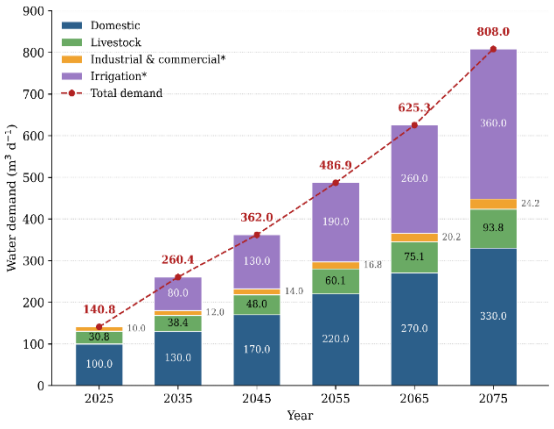
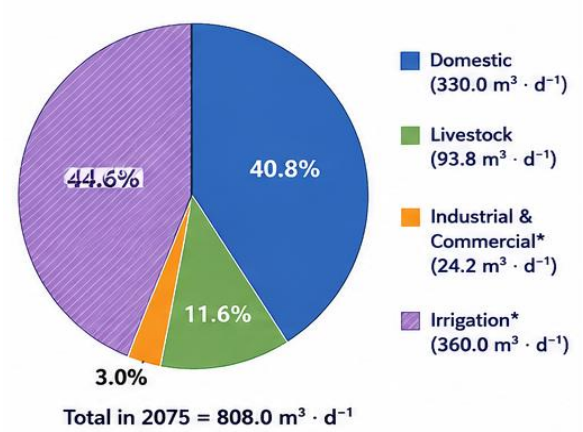


Figure 6
Percentage Contribution of the Demand



4.0 Conclusion and Recommendations

This study developed an integrated framework for assessing present and future water demand within the Muko Reservoir catchment to support sustainable reservoir planning and operation. By combining demographic projections, livestock population forecasts, sectoral water-use assessments, and environmental flow requirements, the study complements the evaporation assessment of Waled *et al.* (2026) and contributes to a more comprehensive understanding of the reservoir water balance. The results demonstrate that reservoir sustainability depends not only on water availability but also on the evolving dynamics of water demand. Domestic water demand is projected to increase from approximately 100 m^3 day^{-1} in 2025 to 330 m^3 day^{-1} by 2075, while livestock demand is expected to rise from 30.75 m^3 day^{-1} to 93.83 m^3 day^{-1}. Consequently, the combined quantified demand increases by more than 220% over the 50-year planning horizon, driven primarily by population growth and livestock expansion. Scenario analysis further indicates that total water demand could reach approximately 808 m^3 day^{-1} by 2075 when irrigation and industrial development are considered, with irrigation emerging as the largest water-use sector. Increasing domestic, agricultural, and livestock demands, together with environmental flow requirements and evaporation losses, will therefore exert growing pressure on reservoir storage and supply reliability, and failure to account for these interacting components may compromise long-term water security and reservoir performance.

Overall, the study provides a robust and transferable methodology for assessing water demand in small reservoirs in semi-arid environments. The framework offers a sound scientific basis for reservoir design, water allocation, and long-term planning and contributes to the implementation of Integrated Water Resources Management (IWRM) principles in Tanzania and comparable regions facing increasing water scarcity under climate and socio-economic change.

It is therefore recommended that future planning for the Muko Reservoir integrate projected water demands with hydrological inflows, evaporation, sedimentation, and environmental flow requirements within a comprehensive water-balance framework. This is particularly important because sediment deposition progressively reduces usable reservoir storage and may constrain the reservoir's capacity to meet projected water demands (Tessema *et al.,* 2024; Lemma *et al.,* 2024). Furthermore, planning should be supported by detailed quantification of irrigation water demand, periodic updating of water-demand datasets, and evaluation of reservoir performance under alternative climate change scenarios. The application of appropriate water-demand forecasting methods can strengthen these assessments by improving the reliability of future demand estimates and supporting informed water-resource planning (Alvisi *et al.,* 2025). These efforts should be complemented by sustained investment in catchment conservation, efficient water-use practices, and the protection of environmental flows within an IWRM framework, thereby enhancing reservoir resilience and water security in the Songwe Region and other semi-arid catchments in Tanzania.

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7.0 Declaration of Conflicting Interests:

The author declares no conflicts of interest.

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