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Assessment of Water Supply and Demand in Walatsi Sub-Catchment, Busia County, Kenya

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Abstract

Overexploitation of water supplies remains the most serious constraint on its sustainability, and many authorities are confronting serious problems in its management because of growing competition for the ever-dwindling natural resource. The study aims to assess the supply and demand for water in the Walatsi sub-catchment from 2022 to 2030. Data from key informants, experiment, direct observations, and GIS analyses were utilized and analyzed through QGIS software and Microsoft Excel, and a decision support system - WEAP model was adopted for scenario analysis and simulations. Using WEAP's built-in supply and demand database, available water supply, present and future water demand, and water balance were determined, and a correlation between simulated water balance and demand was established to interpret water balance results further. Results from the study indicated an annual supply between 31.63 and 31.65 Million cubic meters (Mm^3) and a monthly supply ranging from 0.48 to 6.80 Mm^3. An annual increase in water demand by 27.59% from 6.45 Mm^3 in 2022 was observed, which further revealed a declining annual water balance by −7.07% from 25.18 Mm^3 in 2022 and an increasing annual monthly water deficit in February from −0.02 to −0.15 Mm^3. The −0.999 coefficient explained the unmet demand gap from 0.24% to 1.85%. Variations in monthly supply annually are due to the bimodal dry and rainy seasons, and annual supply is due to regular and leap years. The positive trend in demand is likely to put pressure on available water supplies. An increasing deficit indicates pressure on water sources and exploitation of the reserve. This study, therefore, indicates a water scarcity sub-catchment.

Subject Areas

Supply and Demand of Water in a Sub-Catchment, Sub-Catchment Water Management

Keywords

Water Supply, Water Demand, WEAP Model, Water Balance

1. Introduction

Overexploitation of water supplies remains the most serious constraint on the finite resource that supports life and spurs socio-economic development. Many governments around the world are confronting major problems in freshwater management because of growing competition for the dwindling natural resource [1]. Therefore, the relationship between humans and their natural environment needs some improvement to minimize the threats (scarcity, pollution, and flooding) the precious resource poses to millions of lives and causes billions of economic losses yearly [2]. The world of water is fast changing due to a growing global population, increasing wealth-driven demand, and corresponding increases in pressure on the ecological environment exacerbated by climate change [2]. High water demands cause water stress, which has a detrimental influence on economic development and agricultural productivity.

Water resources in Sub-Saharan Africa (SSA) are highly varied, with, on average, a relatively low supply per capita [3]. Due to population growth, Kenya's per capita renewable water resource is predicted to drop from 1000 to 500 m^3 of absolute water shortage limit per annum by 2030 [4].

Walatsi sub-catchment in Western Kenya is a valuable hydrological system, serving Bungoma and Busia counties and contributing to the Sio River. Increasing demand for water and the inappropriate use of natural resources are substantially putting pressure on water volume, jeopardizing the livelihoods of growing populations that depend upon it as the only water supply, particularly during dry seasons. Therefore, an assessment of water supply and demand was critical for informing proper management decisions. This study focused on specific demand (domestic, livestock, institutional, industrial, irrigation, and reserve) within the sub-catchment and generated information projected to the year 2030, providing comprehensive knowledge for decisions to manage water resources sustainably.

The application of the WEAP model in water supply and demand studies has generally been successful since the tool can analyze scenarios to determine the best management solutions for water use [5]. This study, therefore, used the model to achieve a desirable outcome for sustainable water management in the study area.

Sustainable Water Management (SWM) involves the management of current water resources to sustain ecological, social, and economic growth for current and future generations. It involves an understanding of the past, an evaluation of the current situation, and the formulation of management scenarios for the existing resources in the future. By using the WEAP model, the SWM concept was operationalized in this study, as illustrated in **Figure 1**.

The sub-catchment, being in a water-scarce area, experiences water conflicts annually due to increased water demand from population growth and intensive agricultural development, among other demands [6] [7]. Climate change has also aggravated the water scarcity situation [8]. According to Dindi [6], people's

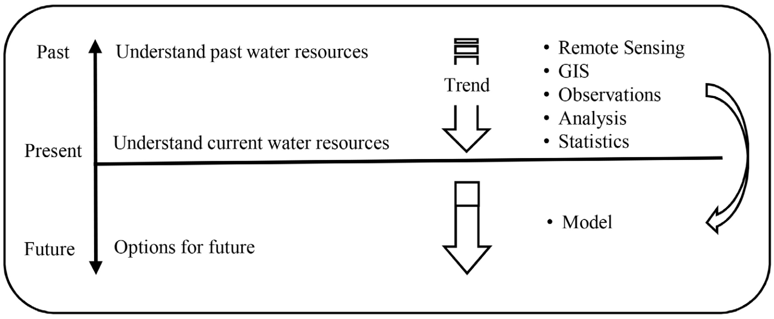

Figure 1. The concept of scenario analysis using simulation models. Source: Loon *et al.* [9].

social well-being and food security in the sub-catchment have been negatively affected due to the conflicts. Therefore, the sub-catchment must design a strategy for the sustainable management of its water resources by fully exploiting all water resources available. The study results will provide information to stakeholders and institutions to aid in solving the sub-catchment's perennial water challenges.

2. Materials and Methods

2.1. Study Area Description

Walatsi sub-catchment, bounded by 34˚10'0"E and 34˚35'0"E longitudes and 0˚25'0"N and 0˚40'0"N latitudes, is approximately 423 km^2 with an altitude range of 1180 m to 1532 m above sea level. It comprises ten micro-catchments and hosts commercial centers (small urban) along main roads (tarmac) and other roads (mostly murram), as shown in **Figure 2**.

The area experiences bimodal rain (Mar. to May, Sept. to Nov.) and dry (Dec. to Feb., Jun. to Aug.) seasons. Rain, an essential input to the overall water supply, greatly impacts human activity, natural vegetation, surface runoff, and groundwater recharge. Annual rainfall ranges from 1091 to 1840 mm, and the average monthly total is from 47 mm to 235 mm. Annual mean maximum temperature ranges from 32.34˚C to 38.15˚C, and yearly monthly evaporation ranges from 2056 to 2303 mm.

Its geology includes Mumias Granites and the Kavirondian system [10]. Soils formed on granites dominate the study area. It is enclosed by agroecological zones Upper Midland (UM) to Lower Midland (LM), suitable for agriculture, infrastructure and settlement, forest and natural vegetation, and other commercial activities [11]. It derives its economic activities mainly from agriculture, sand harvesting, and trade.

The sub-catchment has a population of 268,089 people with a density of 400 to 700 persons/km^2 and a growth rate of 2.3% per annum [12]. Most people live in rural areas where rivers and other available water sources strongly influence their food security and social well-being. A small percentage of households and institutions are connected to piped water served by various water distribution schemes.

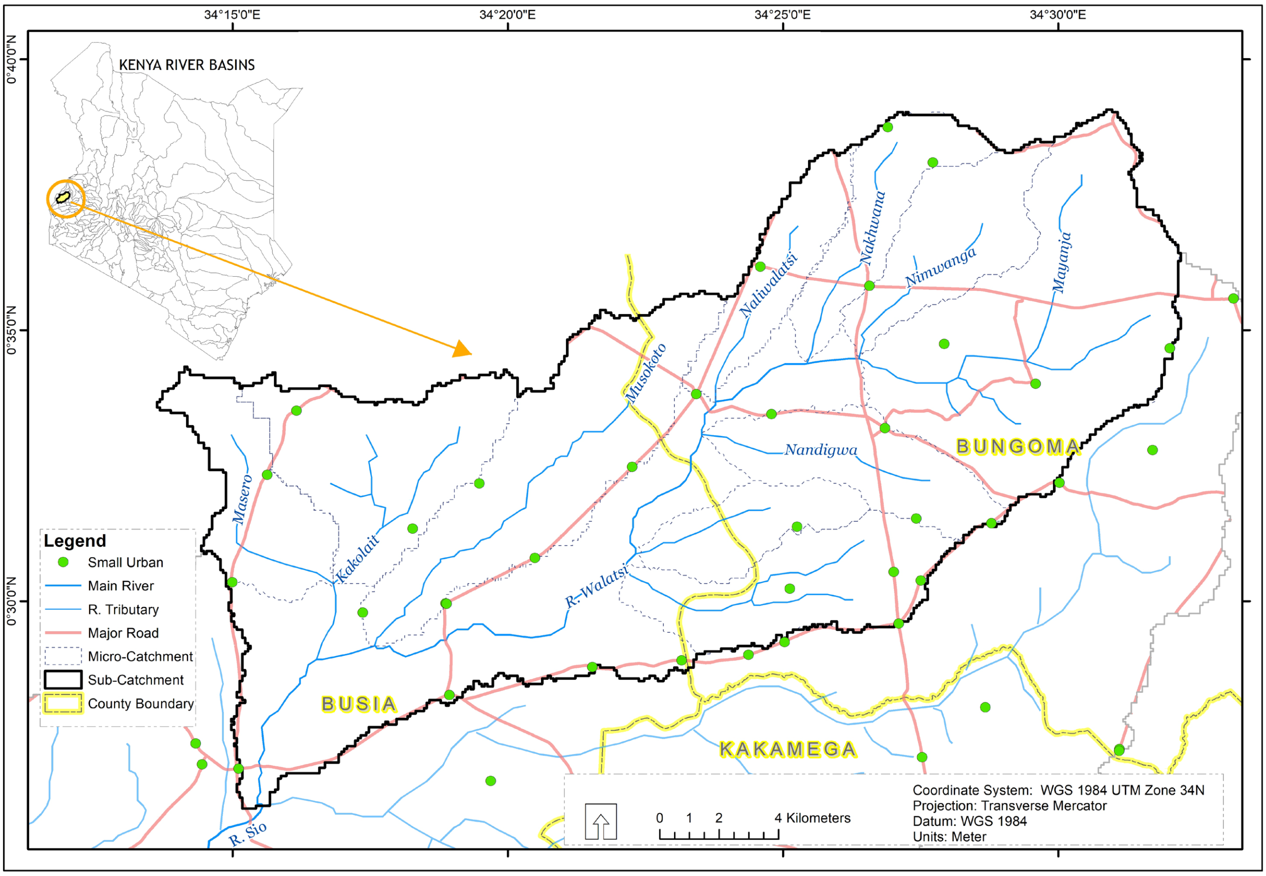

Figure 2. Map of Walatsi sub-catchment.

Surface water is drawn from the Walatsi River system, with tributaries drawing water from micro-catchments in valleys where springs originate. Groundwater from aquifers is drawn through deep and shallow wells and scoop holes. Water tanks and pans constitute storage facilities.

2.2. Data Collection

Data sources included key informant interviews, geographic coordinates of water points, direct observation of geographic features, streamflow measurements, GIS analyses, and published sources, as summarized in Table 1.

2.3. Data Analysis

Quantum Geographical Information System[1] (QGIS) software delineated catchments and its geostatistical tools for GIS analyses and mapping various sub-catchment water demands, supplies, and land cover. Microsoft Excel was deployed in data and statistical analyses, and WEAP modeling software utilized GIS and Microsoft Excel analyses to achieve the study goal.

2.3.1. Water Supply

Surface water estimates were established through river flow analysis using data

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[1] QGIS is open-source (free) geographic information system (GIS) software for geographical analyses.

Table 1. Targeted datasets and sources.

Dataset	Type	Source
Water supply	Surface water, groundwater, and water storage	Water Resources Authority, experiment, and sub-counties
Water demand	Irrigation, livestock, institutional, domestic, industrial.	Government-lined ministries at sub-county level
GIS, RS and weather	DEM, landsat satellite image (landcover), administration boundaries, urban areas, infra-structure.	Internet
	Geographic coordinates	Field observations
	Rainfall, temperature and evaporation	Internet and literature review

from regular gauge station 1AH (1958-2019) and "Equation (1)" [13] and evaluated by the streamflow experimental results. Flow Duration Curve (FDC) was derived and portioned into percentiles that correspond to the standards of river flow analyses and water apportionment in Kenya [14], where Q95 represents flow levels that exceed 95% of the time and are conserved for the reserve (environmental flows), Q80 represents allocable flows for domestic water supply and Q50 for irrigation purposes.

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gaged}} \times Q_{gaged} \tag{1}$$

where: $Q_{ungaged}$ - Flow at the ungauged location. Q_{gaged} - Flow at surrogate gauge station. $A_{ungaged}$ - Drainage area of the ungauged location. A_{gaged} - Drainage area at surrogate gauge station.

Summation of abstraction yields from the boreholes and statistical yield estimates from the shallow wells and scoop holes was done to give the total allocable volume of groundwater available. Statistical estimates of the capacities of water storage facilities (relied on in dry seasons) established allocable volumes in storage. Water losses through evaporation (majorly on water pans) were computed using "Equation (2)" [15].

$$\boldsymbol{E}_{vol} = \boldsymbol{A}_{max} \times \boldsymbol{E}_{o} \times 10 \tag{2}$$

where: $\boldsymbol{E}_{vol}$ - Maximum evaporative losses (m^3/day). $\boldsymbol{A}_{max}$ - Maximum reservoir surface area (ha). $\boldsymbol{E}_{o}$ - Open water evaporation (mm/day) as defined by the average over the dry season months.

2.3.2. Water Demand

Cross-area aggregation (Areal Weighted, AW) interpolation technique [16] [17] was applied through GIS to datasets whose granularity did not correspond to the delineated sub-catchment boundary to achieve the desired analyses. Haque *et al.*'s [18] discrete model "Equation (3)" was adopted for demand projection using established rates. Water demand scenarios were developed based on the data gathered in the WEAP model for a better understanding of the current and future water situation.

$$P_t = P_0 \left(1 + r\right)^t \tag{3}$$

where: P_0 - Current population. P_t -Population after time t. r - Growth rate.

Domestic demand, for instance, was established through the human population, the units in Table 2, and its forecast through "Equation (3)". Livestock and poultry demand were measured using respective established numbers and units in Table 2, and future estimates using annual regions' consumption rates through "Equation (3)". Irrigation, institutional, and industrial demand were based on allocable water units and data established.

2.3.3. Water Balance

The WEAP model was adopted to simulate and develop water balance in the sub-catchment. The model was calibrated and validated using established apportionable water supply, and water demand data, and by using a built-in supply and demand database, established growth rates, and considering the scenarios developed in Section 2.3.2, water balance simulations were executed to the year 2030. 2022 was used as a current account for comparisons and future estimates.

The model adopted a modified localised sub-catchment water balance in "Equation (4)".

$$\begin{aligned}&\text{Water Balance}\\&= \text{Available}\left(\text{apportionable}\right)\text{Water} - \left(\text{Summation of all Water Demands}\right)\end{aligned} \tag{4}$$

Table 2. Domestic, livestock, poultry and institution unit water requirement in Walatsi sub-catchment.

Consumer	Unit	Rural Areas (High Potential)	Urban Areas (Low Class Housing)
People with connections	1/head/day		75
People without connections	1/head/day	20	20
Livestock Unit (LSU)	1/LSU/day	50	
Boarding schools	1/head/day	50	
Day (colleges)	1/head/day	25	
Day (primary and secondary schools)	1/head/day	5	
Dispensaries and health center	1/day	5000	
Hotels (medium class)	1/bed/day	3000	
Bars	l/day	500	
Shops	l/day	100	
Administration offices	l/head/day	25	

a. LSU Conversions: (1 grade cow/3indigenous cows or pigs/15sheep or goats/5donkeys/50rabbits/165 poultry) = 1 Livestock Unit (LSU) = 50 l/head/day.

Source: Compiled from MWIS [15].

Where: *Available* (*Apportionable*) *water* - Surface (after preserving the reserve quantities), storage and groundwater quantities. *Demands* - Identified water needs now and in the future.

Source: Adapted from WRMA and WSTF [19].

To further interpret the model results, relationship analysis between its outputs (the water balance and water demand) was useful in understanding the behaviour of the variables for appropriate decisions. This was done through Pearson's correlation "Equation (5)" [20].

$$r_{xy} = \frac{\sum (x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum (x_i - x)^2 \sum (y_i - \overline{y})^2}} \tag{5}$$

where: r_{xy} - Correlation coefficient of the linear relationship between the variables x and y. x_i - Values of the x-variable in a sample. $\overline{x}$ - Mean of the values of the x-variable. y_i - Values of the y-variable in a sample. $\overline{y}$ - Mean of the values of the y-variable.

3. Results

3.1. Water Supply

3.1.1. Water (Re)Sources Distribution

The distribution of ground and surface water (re)sources in the sub-catchment is shown in Figure 3.

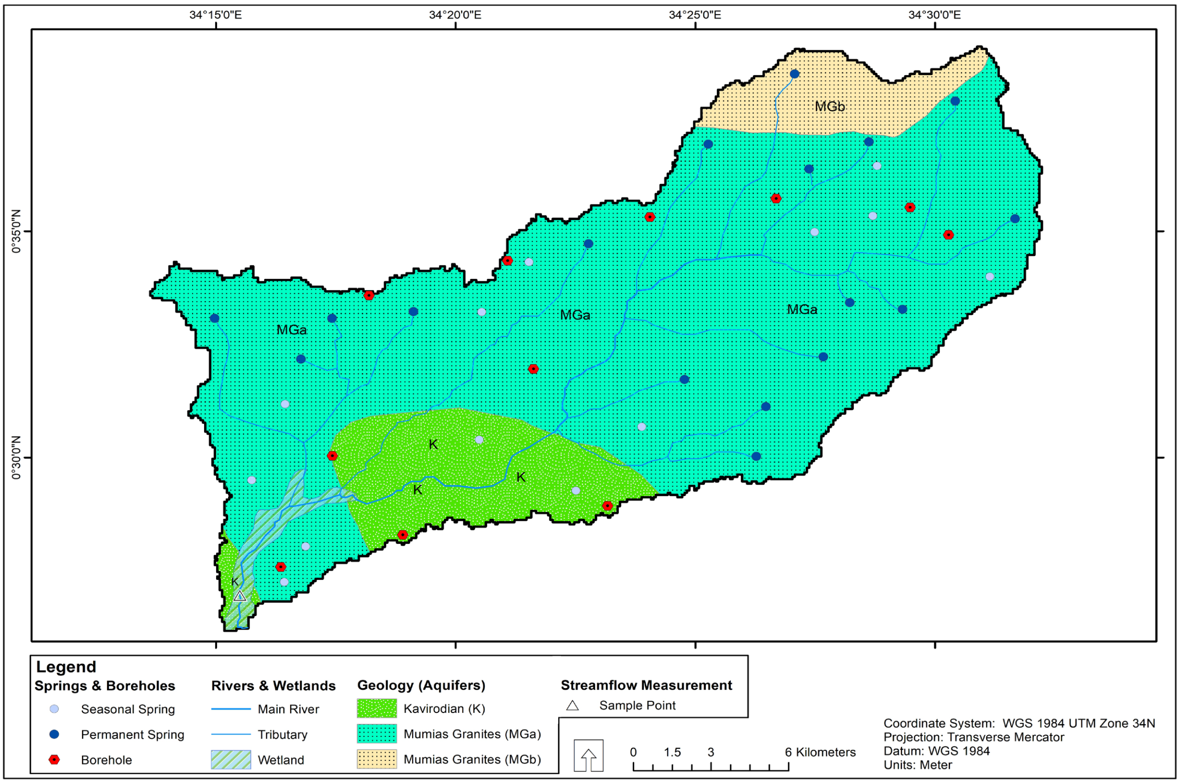


Figure 3. Map of the water (re)sources in Walatsi.

3.1.2. Water Supply Estimation

The sub-catchment water supply was established from surface, ground, and storage sources as follows:

1) Surface Water

Surface water was established from river flow analysis. The outcome of the streamflow experiment conducted at the mapped sample point in Figure 3 is illustrated in Figure 4. Figure 5 and Figure 6 show the average monthly and apportionable flow, respectively, while Figure 7 shows the estimated average monthly volume noted in an ordinary year.

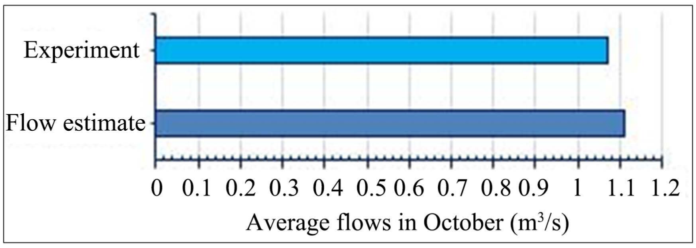


Figure 4. Experiment and flow estimate comparison.

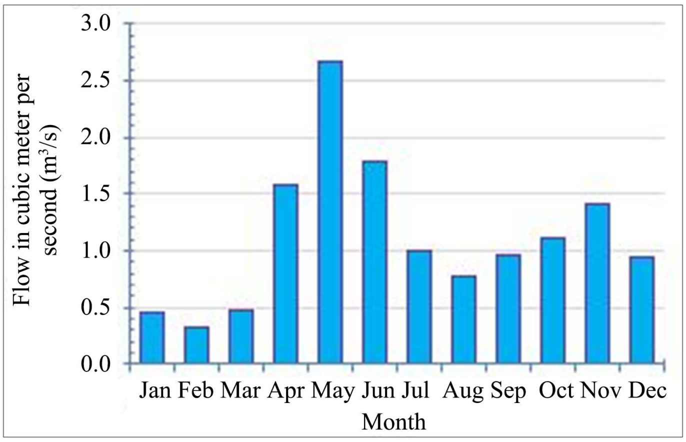


Figure 5. Average monthly flow in Walatsi sub-catchment.

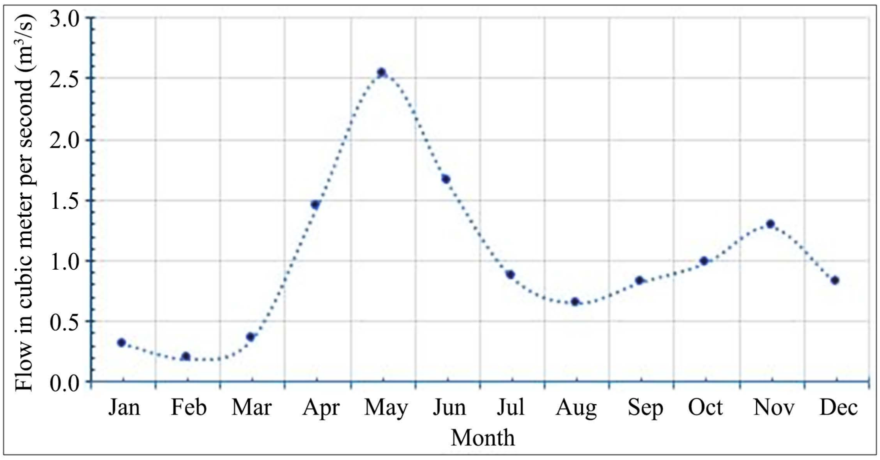


Figure 6. Average monthly flow (apportionable water) in Walatsi sub-catchment.

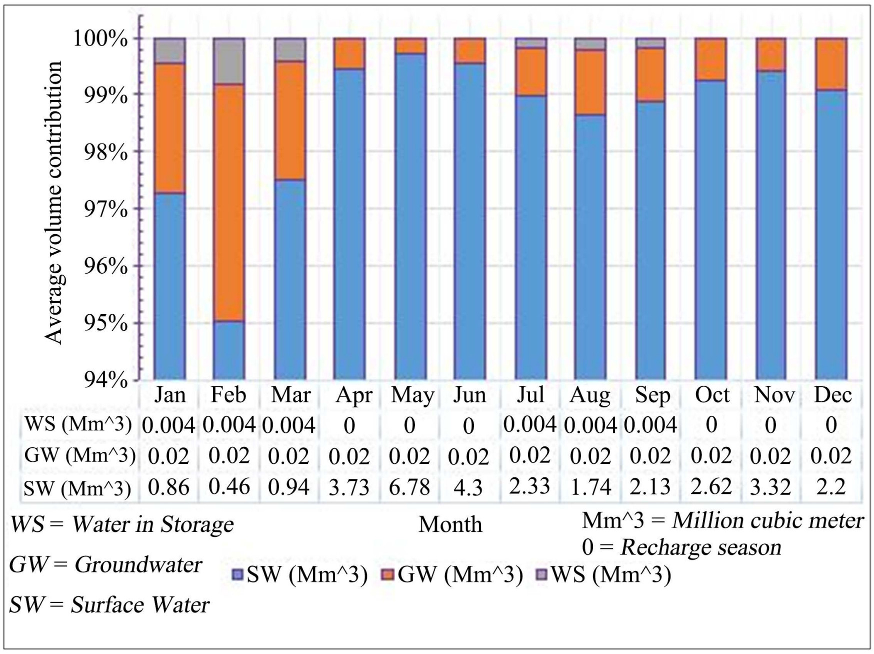


Figure 7. Water sources average monthly supply per year for a normal year.

2) Groundwater and Water in Storage

The estimated monthly average allocable groundwater in a regular year and monthly average water in storage results are in **Figure 7**.

3.1.3. Summary of Established Water Supply

Total average monthly supplies in a regular year and total annual supplies in a regular and leap year for the entire study period are shown in **Figure 8** and **Table 3**, respectively.

3.2. Water Demand

3.2.1. Water Demand and Distribution

The analysis of land use activities, which also informed the demand, is presented in **Table 4**. The activities were linked to the satellite image map of vegetation cover in **Figure 9** and, later, the water distribution schemes, institutions, and households map in **Figure 10**.

3.2.2. Business-As-Usual and Planned Development Scenarios

The Business-As-Usual Scenario (BUS) and Planned Development Scenario (PDS) annual water demand analyzed for the entire study period is presented in **Figure 11**, and the percentage yearly trend for the same period is in **Figure 12**.

3.3. Water Balance

3.3.1. BUS and PDS Monthly and Annual Water Balance

Figure 13 shows the monthly water balance, and **Table 5** shows the annual monthly water deficit. The yearly water balance is shown in **Figure 14**, and its annual percentage trend for the entire study period is in **Figure 15**.

Table 3. Total annual water (allocable) supply in Walatsi sub-catchment.

Water Source Annual Forecast	2022	2025	2028	2030
Surface water (Mm^3/year)	31.40	31.40	31.42	31.40
Groundwater (Mm^3/year)	0.20	0.20	0.21	0.20
Water in storage (Mm^3/year)	0.03	0.03	0.03	0.03
Sum (Million m^3/year)	31.63	31.63	31.65	31.63

Table 4. Land use in Walatsi sub-catchment.

Agro-Ecological Zone (AEZ) (**Figure 9**)	Land Use Activities	Vegetation Cover (**Figure 9**)
AEZ UM2-UM4) Alt. 1500 - 1532 m	Agriculture and its prospects (Maize, coffee, and sunflower; Horticulture, cereals, legumes, tubers, and fruits; Macadamia nuts, castor; Pasture and forage), Settlement and infrastructure	**Low**. Due to high household density (**Figure 10**), settlement, infrastructure, and agricultural activities
AEZ (LM1-LM2) Alt. 1350 - 1500 m	Agriculture and its prospects (Sugarcane, maize, coffee, sisal, and sunflower ; Horticulture, cereals, legumes, tubers, and fruits; Pasture and forage), Settlement and infrastructure	**Moderate**. Due to high household density (**Figure 10**), settlement, infrastructure, and agricultural activities
AEZ (LM3-LM4) Alt. 1180 - 1350 m	Agriculture and its prospects (Sugarcane, cotton, maize, sisal, sunflower, and tobacco; Horticulture, cereals, legumes, tubers, and fruits; Pasture and forage), Settlement and infrastructure	**Dense, moderate, and low**. Due to varying household densities (**Figure 10**) and density of activities (agriculture, settlement, infrastructure) attached to such variation. **Dense** along the river line and wetland (**Figure 3** and **Figure 9**) and also due to moderate to high rainfall.

Source: Compiled from Jaetzold and Schmidt [11] and the GIS Landsat 8 satellite image map in **Figure 9**.

Table 5. BUS and PDS annual monthly water deficit.

Scenario Forecast	2022	2023	2024	2025	2026	2027	2028	2029	2030
BUS: Feb. (Mm^3)	−0.02	−0.02	−0.03	−0.04	−0.05	−0.06	−0.07	−0.08	−0.09
PDS: Feb. (Mm^3)	−0.02	−0.05	−0.06	−0.06	−0.12	−0.12	−0.14	−0.14	−0.15
Deficit (%)	0	−150	−100	−50	−140	−100	−100	−75	−67

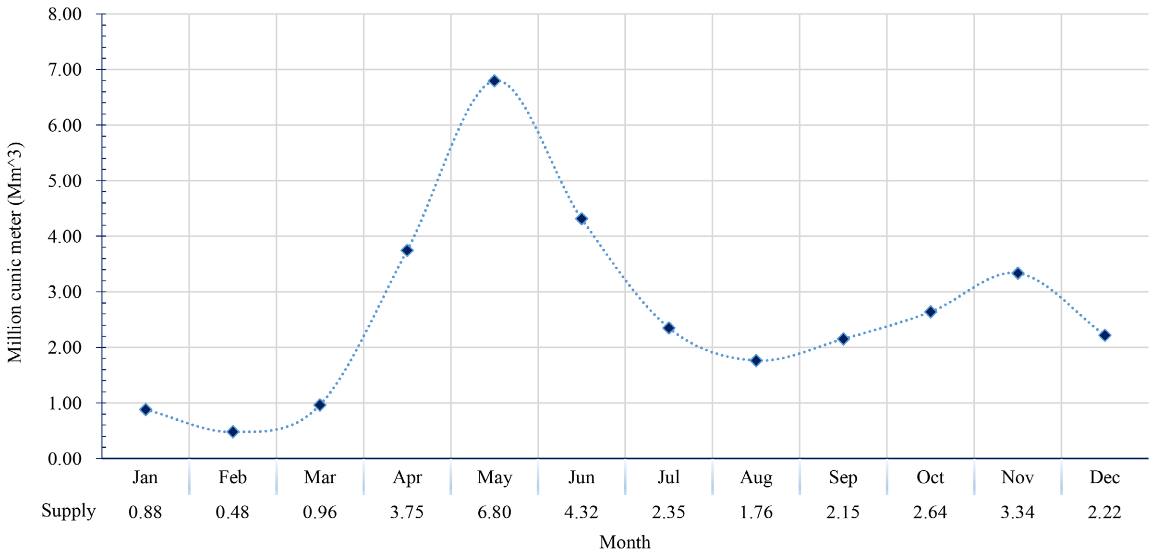


Figure 8. Total average monthly water supply per year for a normal year.

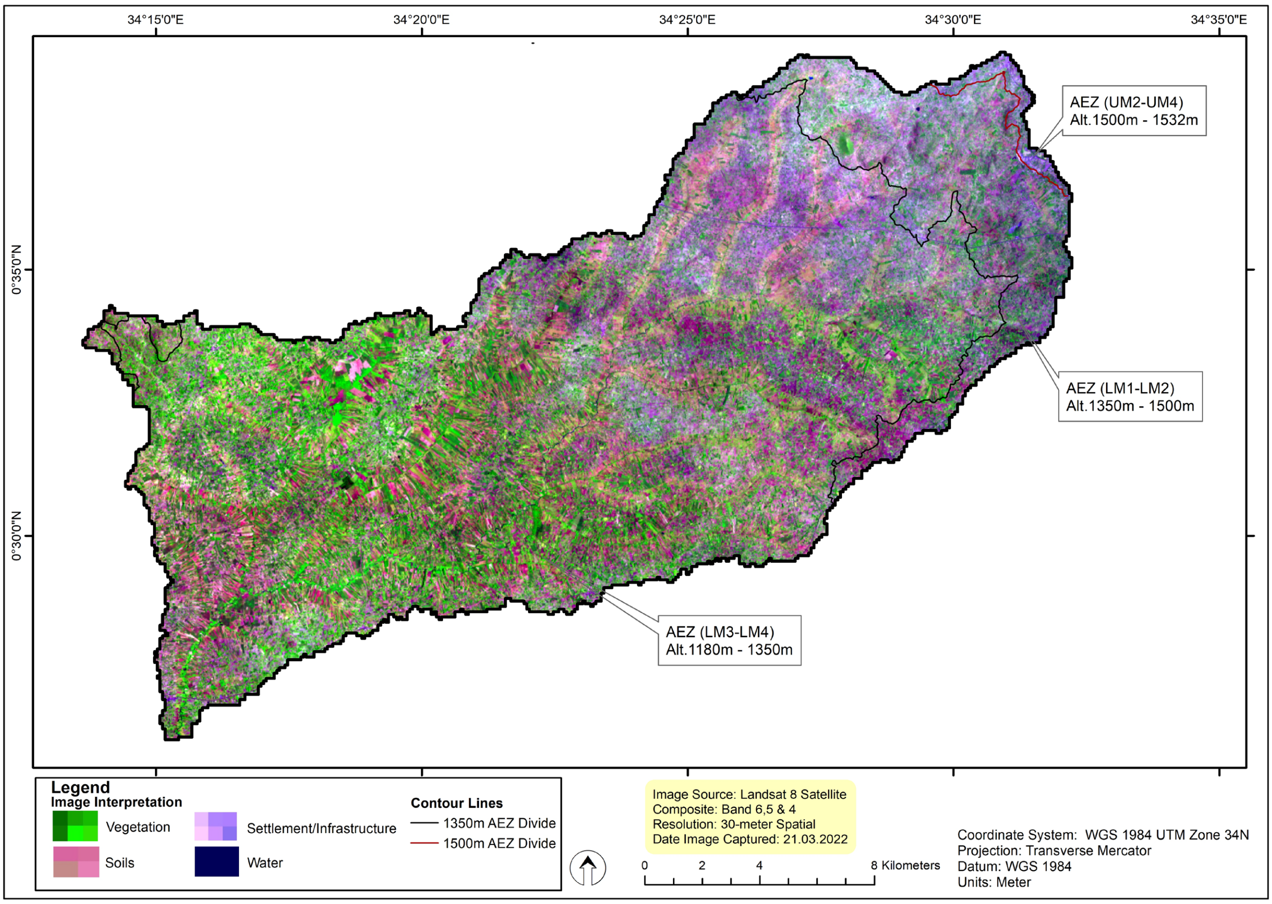


Figure 9. Vegetated and exposed areas.

3.3.2. Correlation Analysis and Unmet Demand

Figure 16 shows the correlation between the water balance and demand in PDS, while **Figure 17** illustrates the annual unmet water demand in BUS and PDS.

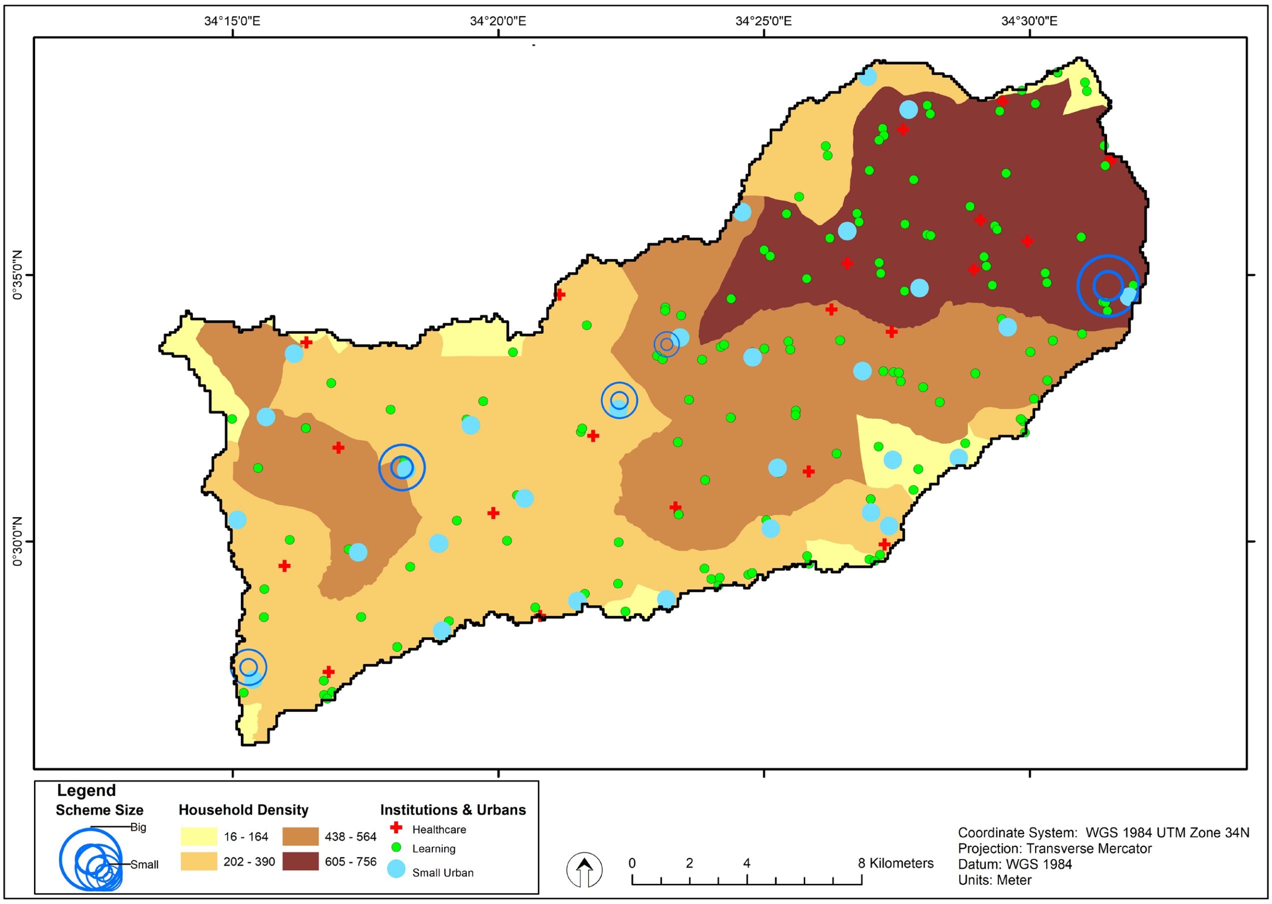


Figure 10. Water distribution schemes, institutions and households.

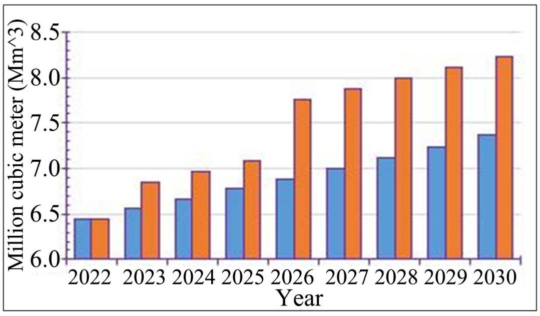


Figure 11. BUS and PDS annual water demand forecast.

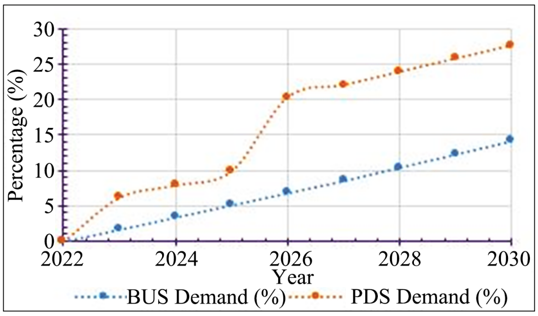
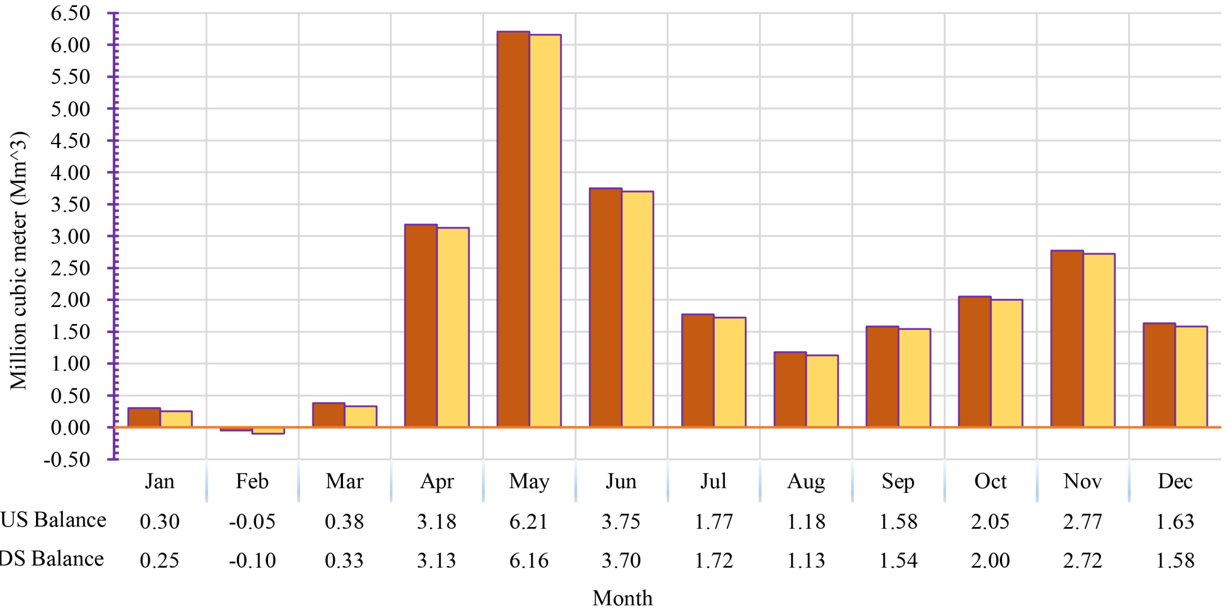


Figure 12. BUS and PDS annual water demand trend.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ BUS Balance	0.30	-0.05	0.38	3.18	6.21	3.75	1.77	1.18	1.58	2.05	2.77	1.63
□ PDS Balance	0.25	-0.10	0.33	3.13	6.16	3.70	1.72	1.13	1.54	2.00	2.72	1.58

Figure 13. BUS and PDS overall monthly average water balance (2022-2030).

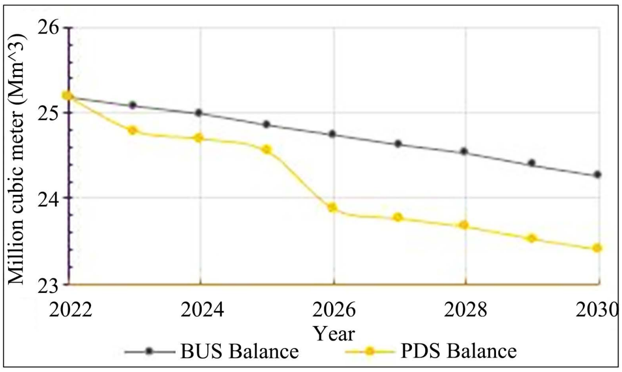


Figure 14. BUS and PDS annual water balance.

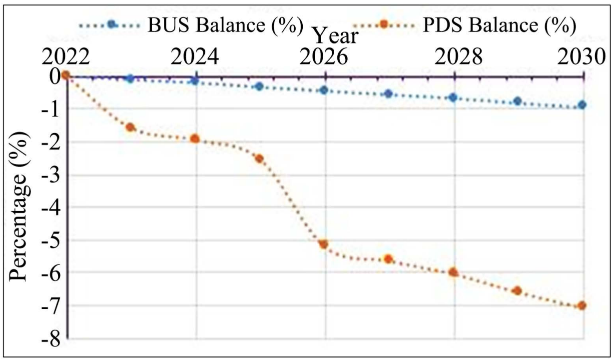


Figure 15. BUS and PDS percentage annual water balance trend.

4. Discussions

4.1. Water Supply

Surface water comprised water in the river system (stretching over a 144-kilometer network) made of wetlands, springs, tributaries, and the main river (**Figure 3**); groundwater covered water from scoop holes, shallow wells, and deep wells (boreholes) that was drawn from Mumias granites and Kavirondian aquifers [10] on which the study area sits (**Figure 3**); and storage included harvested rainwater stored in water tanks and water pans.

Derived from the FDC and **Figure 5**, **Figure 6** shows apportionable surface water after reserve allocation. The results of the study experiment in **Figure 4** conducted in early October of 1.07 m^3/s fell short of 0.04 m^3/s of the average monthly flow estimates, attributable to the period of onset of a rainy season. The results were key in affirming the flow estimates. Q95, by allocation standards [14], represented 0.13 m^3/s, Q80 0.30 m^3/s, and Q50 0.65 m^3/s. **Figure 6** results as an input in the WEAP model established monthly averages ranging from 0.46 to 6.78 Mm^3 per year in a normal year. The monthly regular flow pattern in **Figure 5** depicts the bimodal rainy and dry seasons experienced according to Jaetzold and Schmidt [11] and NASA [21]. Allocable groundwater was estimated at 0.02 Mm^3, and water in storage (utilizable in dry seasons) was estimated at 0.004 Mm^3 average monthly supplies, respectively, in a normal year. Total average monthly supplies ranged from 0.48 to 6.80 Mm^3 in a normal year, and total annual supplies in a regular year were estimated at 31.63 Mm^3 and for a leap year at 31.65 Mm^3 for the entire study period. The established apportionable water supply in the sub-catchment is summarized in **Figure 8** and **Table 3**. Water loss estimates through evaporation were insignificant and, therefore, negligible. Surface water is the predominant and main source.

There was no evidence of strategies in the region's development plans to increase the number of water supply sources; therefore, the study assumed the established water amounts as dependable monthly and annually for allocation purposes throughout the study period.

4.2. Water Demand

Six types of demand identified were domestic, institutional, livestock, poultry, industrial, and irrigation. The demand was also confirmed by the land use analysis in **Table 4** and **Figure 9**. According to Onyango *et al.* [22], due to pressure from increasing population and occasioned demands in the region, land coverage for built-up areas is increasing while that for forests is decreasing, this was in agreement with the outcome of demand analyses.

The distribution of demand magnitudes in the sub-catchment is influenced by the spreading of household densities, small urban areas, health and learning institutions, and water distribution schemes, as shown in **Figure 10**. For instance, high household densities translate to high water needs, and access to piped water through various schemes means high water usage. The presence of small urban areas and institutions also attracts more water demand.

The study adopted two scenarios for demand and water balance simulations in the model: BUS and the PDS. BUS considered the current established demand with predefined growth rates and projections. In contrast, PDS looked into the new developments (demand) to be implemented as outlined in the development strategies alongside the BUS demand to give an overall picture of what the water use situation would be in the sub-catchment.

The outcome in **Figure 11** showed growth in annual water demand from 6.45 Mm^3 in 2022 to 7.36 Mm^3 in 2030 in BUS and 8.23 Mm^3 in PDS. PDS results in **Figure 12** indicated a growth of 13.49% by 2030 from the BUS demand and by 27.59% from 6.45 Mm^3 in 2022. The spike in PDS is attributed to the implementation of the planned projects (irrigation and domestic distribution schemes between 2023 and 2026). The overall average monthly demand in BUS ranged from 0.53 to 0.59 Mm^3 and from 0.58 to 0.63 Mm^3 in PDS for the entire study period.

4.3. Water Balance

The results in both scenarios showed an overall monthly water balance that ranged on average from −0.05 to 6.21 in BUS and −0.10 to 6.16 Mm^3 in PDS (**Figure 13**), with February recording a negative balance. The negative water balance implies a deficit in water supply linked to competition for scarce water resource, eventually leading to conflicts [6] [23]. Further inquiry into the negative balance revealed an annual increasing deficit trend to 2030 in February, whose estimation is vital in planning various interventions to normalize the water balance. The annual deficit trend (in February) ranged from −0.02 (2022) to −0.09 (2030) in BUS and −0.02 (2022) to −0.15 (2030) Mm^3 in PDS (**Table 5**).

Comparatively, the annual deficit in PDS grew by −67% in 2030 from BUS. Further, **Table 5** demonstrates the deficit annual trend of PDS from BUS, with spike years in negative water balance in 2023 and 2026 when the envisaged development strategies were implemented; other years reflected expected trend deficits emanating from various applied demand growth rates. The model output (**Figure 14**) further showed an annual drop of the water balance from 25.18 in 2022 to 24.27 Mm^3 in 2030 for BUS and 25.18 in 2022 to 23.40 Mm^3 in 2030 for PDS; this represented a −0.94% drop in 2030 in BUS and −7.07% in 2030 in PDS, respectively (**Figure 15**).

The correlation between water balance and demand results was −0.999 in BUS and −0.9999 in PDS. The trendlines in **Figure 16** illustrate the relationship in PDS. The results established a solid negative correlation in that there is an equivalent decrease in water balance with an increase in water demand in the sub-catchment, crucial information for strategies to manage water resources sustainably.

The negative water balance represents the volume of demand that goes unmet by the supply. All the demand types were treated with the same priority level, and the resultant unmet volumes were distributed, as shown in **Figure 17**. From the results, the percentage of unmet demand grew (steadily) annually from 0.24% (2022) to 1.16% (2030) in BUS, while in PDS, it rose (significantly) from 0.24% to 1.85%. The results indicate that the growth in demand led to a negative water balance. The solid negative correlation supported the unmet demand gap,

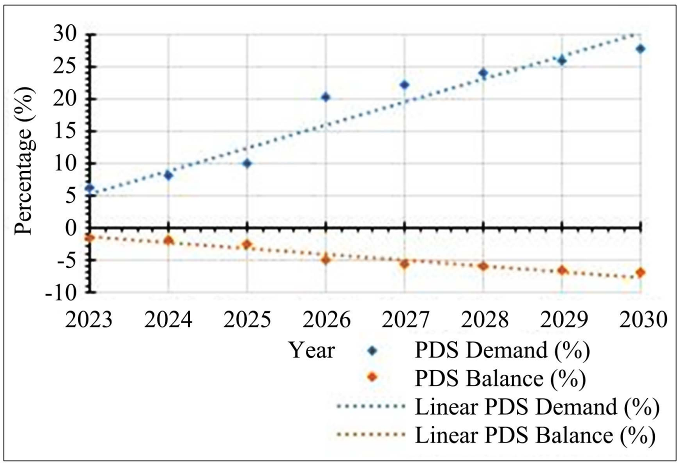


Figure 16. PDS water demand and water balance correlation trend-line.

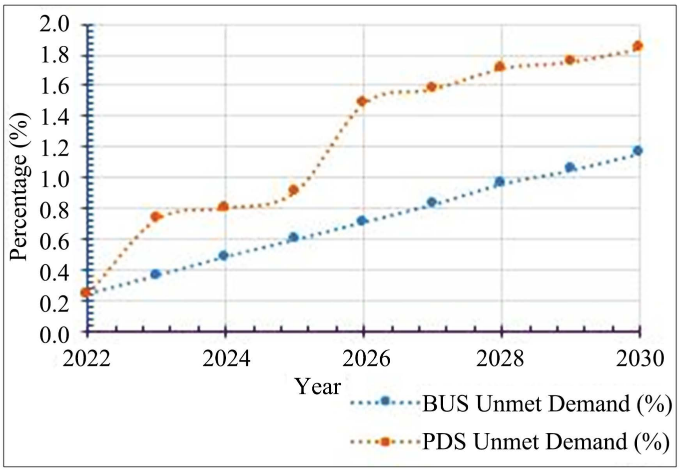


Figure 17. BUS and PDS annual unmet demand.

which meant exploitation of the reserve, detrimental to its dependents like the aquatic ecosystem [24].

5. Conclusions

The available (apportionable) water supply in the sub-catchment varies from 31.63 to 31.65 Mm^3 per year in regular and leap years, respectively, while monthly supplies range from 0.48 (February) to 6.80 (May) Mm^3 on average per year in regular years for the entire study period. The variations in monthly water supply are attributed to the bimodal dry and rainy seasons experienced annually in the sub-catchment. The month of February stands to be the driest, thus negatively affecting the supply of surface, sub-surface (shallow wells and scoop holes), and storage water sources. The study notes surface water as the predominant and main source of water for various needs in the sub-catchment. Groundwater and water in storage supplies contribute minimally to the overall water supply in the sub-catchment, which sits on capable aquifers of good water yields.

The current (2022) annual water demand in the BUS scenario is 6.45 Mm^3, and the future water needs are 7.36 Mm^3, equivalent to a growth of 14.12%[2] in 2030. The overall sub-catchment annual current and future water demand, based on the PDS scenario, will rise by 27.59% from the current 6.45 to 8.23 Mm^3 in 2030. Through the scenarios, the study establishes a positive trend in the water demand within the study period, a trajectory likely to put pressure on available water supplies and result in conflicts of resource use when the supply is limited.

The water balance indicates an increasing trend of water deficit in February, annually in both scenarios, that is, from −0.02 in 2022 to −0.09 Mm^3 in 2030 in BUS and −0.15 Mm^3 in 2030 in PDS. It also indicates an annual decline in BUS by −3.61% in 2030 and an overall annual decline of −7.07% in 2030 from 25.18 Mm^3 in 2022 in PDS. The study establishes a strong negative correlation of −0.999 between the water balance and demand, which confirms the increasing declining balance with demand increase within the study period. The increasing trend of unmet water demand by 1.16% from 0.24% in 2030 in BUS and, overall, by 1.85% from 0.24% in 2030 in PDS also affirms the aforementioned relationship. The unmet water demand, therefore, explains the water shortages and related conflicts reported in some parts of the sub-catchment due to pressure on available supply by the growing demand. It also indicates an exploitation of the reserve, which is detrimental to its dependents, like the aquatic ecosystem, and the need to explore alternative water sources and strategies to meet the demand.

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Conflicts of Interest

We declare no conflicts of interest regarding the publication of this paper.

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[2] 14.12% growth in WEAP model (BUS scenario) represents overall growth based on individual (demand) projected growths estimated from established rates in Section 2.3.2.

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