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Sustainability of Raw Water Supply in Nawuni River for Tamale Metropolis and Environs, Ghana

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Abstract
Water supply service is possibly the most essential of all public service in Ghana and any obstruction to its delivery threatens human survival. A major challenge to water supply is the rapid urbanisation, which has increased water demand in the urban areas, placing pressure on service providers to meet demand. Perennial water shortages in Tamale, is linked to several factors including the inability of the service provider to keep pace with the demand of the rapidly increasing population of the city. This situation could be exacerbated by natural climate variation and competing water uses upstream the city supply source. This study investigates the sustainability of raw water supply to Tamale metropolis and environs using Water Evaluation and Planning Model (WEAP). The investigation was based on scenarios analysis: Reference scenario, Population and Socio-economic growth, intensifying upstream water use and Extended Dry Climate. The results revealed that, intensifying upstream water use as projected in the study do not have impact on the downstream water availability for sustainable water supply. However, the assessment based on High Population and Socio-economic growth results showed significant value (229 million cubic meter) of Unmet Demand in year 2035 for Urban and rural demand site. The results also showed that, the water demand will outstrip raw water supply by 2029 when Extended Dry Climate occurred under scenario High population and Socio-economic growth. Possible options of water storage reservoir should be investigated so as to mitigate the effect of extended dry season.
Keywords: Downstream water, Reliability, Supply requirement, Supply delivered, Un-met demand.
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1. Introduction

Water is a fundamental resource and supports life. Lack of access to portable water does not only threaten human survival, but negatively impacts economic development. Over the years, water has been considered unlimited in quantity and available as required. However, population growth, pollution of water bodies and rapid economic development coupled with changes in climatic conditions have resulted in stress on the existing water bodies (IBWRD, 2014).

Water demand for domestic activities is driven to a large extent by the population growth and the industrial demand by the expansion of industries for socio-economic development (van Drunen *et al.,* 2006). As the economy grows, people's income increases and in turn lead to changes in lifestyle. This is often accompanied by an increased in water consumption.

The direct impact of economic and population growth is not the only reason for concern when it comes to future fresh water scarcity, however, the impacts of climate change on the future water availability is also crucial. It has been predicted with high confidence (scale of confidence of 8 out of 10) that climate change will exacerbate the water stress situation in some countries (Bates *et al., 2008*); while introducing water stress to countries that do not experience it (Boko *et al.,* 2007).

Though Ghana can be described as having abundant freshwater resources, Per capita available fresh water in the country is declining. In 1955, the per capita available fresh water declined from 9,204m^3 to 3,529m^3 in 1990 (Karikari, 1996). This is projected to further decline to 1,400m^3 by 2025 (Asare, 2004). Besides, Volta River and its tributaries, which are an important source of water for inhabitants of six riparian states including Ghana (Binice, 2010), are under severe stress due to competing demands on the resources by riparian states and poor climatic conditions (Mul, *et al.,* 2015). Population growth of Ghana and Burkina Faso that cover the largest proportion of the basin has resulted in larger abstraction of water to meet the increasing demand (McCartney *et al.,* 2012).

Most disturbingly, White Volta at Nawuni (Nawuni River), a major tributary of Volta River, which is the only source of potable water for the Tamale Metropolis and environs is under threat. Its depth has reduced dramatically (Benice, 2010), which threatens the capacity of the river to deliver the volume of water required to meet demand in future. Besides, the upscaling of irrigation in the basin has a direct impact on the competing water uses as well as downstream water use and environment (Ofosu, 2011). With the increasing demand coupled with climate change effects call for answers as to whether the resource can sustain the demand. Ghana

Water Company Limited (GWCL) supply water from Nawuni River to about 500,000 people spread across the Tamale Metropolis and four districts (Kumbung, Tolung, Savulugu and Sagnarigu) with the residents of Tamale metropolis being the largest clientele. Thus, lack of access to safe and affordable water comes with public health problems, which needs to be curtailed in order to ensure sustainable livelihoods.

2. Study Area

This study was conducted in the White Volta at Nawuni, which is located about 40km northwest of Tamale (Capital of the Northern Region of Ghana). The White Volta River and its main tributaries in the northern part, take their sources in the central and north-eastern portions of Burkina Faso (WRC, 2008). First, the river flows south to enter Ghana, turns West to be joined by the Red Volta, and continue west through the upper east region and then turns south. From south it flows to Nawuni, flowing west to Daboya then south again where it is joined by the River Mole before entering the Volta Lake (WRC, 2008). Nawuni lies between latitudes 9°351 and 9°451 N and longitudes 1°101 and 1°251W (Figure 2.1).

The surface area of the Nawuni catchment is 106,000 km^2 (McCartney, *et al*., 2012) and about 91,000 km^2 at Nawuni with the total length of 1,140 km of the main channel (Obuobie and Bernd, 2008).

Figure 2.1: Study area showing White Volta (left) and Ghana Water Company abstraction point

The climate is semi-arid to humid with annual rainfall varying from 600 mm in the extreme north of the basin to about 1200 mm in the extreme south (VBRP, 2002) while the mean temperature range between 27-30ºC annually (McCartney, *et al.,* 2012).

3. Methodology

The assessment was based on scenarios analysis using WEAP Model. The mythology is represented in the flow chart below (Figure 2.2). The method involved collection of data on the existing water demand and supply in the study area and followed by establishing current account, which adopts the existing situation of water demand and supply. A default scenario call ''Reference Scenario'' then carries forward the current account into the entire project period (2015-2035). The ''Reference Scenario'' established from the current account simulate the likely evolution of the system without any intervention. And scenarios asking ''what if'' questions were then built to change the ''Reference Scenario'' and analyse the impact of change in policies (SEI, 2015).

Scenarios asking ''what if questions that represent changes in the system and future development included:

Scenario 1: High population and socio-economic growth.

Study conducted by Ofosu (2005) in Kumasi revealed that, 'water demand grows at an exponential rate of 5 % with socio-economic growth contributing 2.74 %'. In this scenario, annual water use rate for domestic, commercial and institutional which link to population was assumed to increase at rate of 2.7 % as a result of industrial and socio-economic growth of Tamale. Under the WEAP manage scenario tool, a scenario is added in order to evaluate the impact of: Increasing population growth rate from 2.9 % to 5 % and 2.7 % increase in urban annual water use rate.

Scenario 2: Competing water uses upstream.

This scenario is added based on the consideration that the current rate of riverine irrigation and small reservoirs development may increase in the future. The small reservoirs for irrigation were considered as consumptive water demand. Small reservoirs have impact on the run off water contributing to the main river flow; because they stored and only release water onto the river during the wet season when full, hence they were considered as demand site. In order to assess the future implication of this development, scenario named "Intensifying upstream water use" is added to look at the impact:

a) If riverine irrigation upstream expands at a rate of 8%.
b) Development of small reservoirs at a rate of 3.1% per year.
c) Implementing the first phase of the proposed large-scale sugarcane irrigation upstream.

Extended Dry Climate scenarios.

The previous scenarios only varied demand and not supply. In order to examine the supply variation and the resources, Water Year Method was used. Water Year Method is a simplified way use to see how variation of natural climate data (streamflow, rainfall) can be considered in WEAP modelling using scenario analyses. The water year sequence created comprises climate variation sequence for the scenario period. The climate sequence is modified and assigned to each of the years of the study period to look at the impact of prolonged drought on water availability for supply under each of the above scenario (Reference, scenario 1 And Scenario 2).

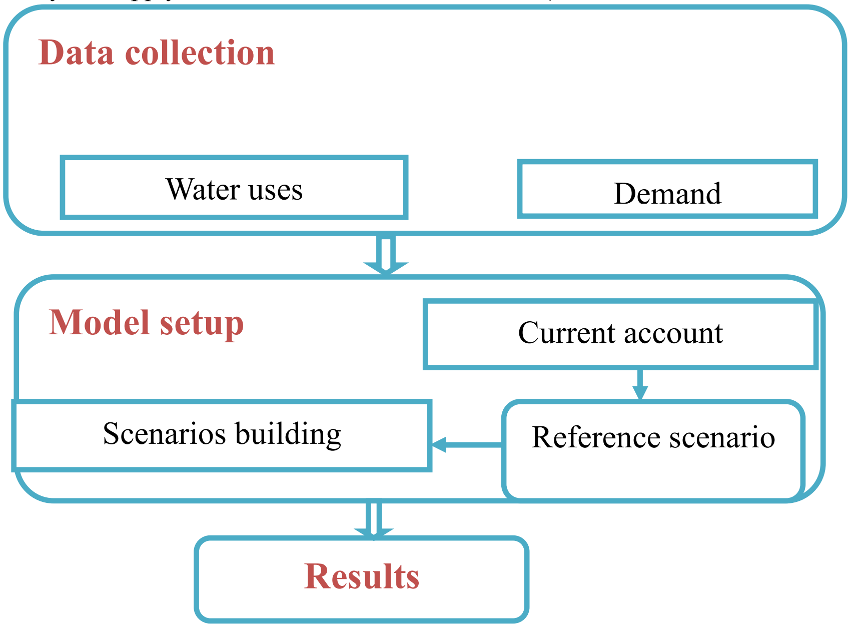

Figure 2.2: Flowchart of methodology

4. Results and Discussion

The analysis considers the increasing demands for water resulting from socio-economic and population growth, Extended Dry Climate and competing water uses upstream Nawuni catchment; and the implication of future trend. Using WEAP, the alternative assumptions are evaluated which aimed at possible future situations in the year 2035. The output analysed include: supply requirement, supply delivered, unmet demand and reliability with regard to the alternative assumptions made.

However, the water uses and allocation modelling were restricted to surface water resources only in this study. Also, the scenarios analysis considered only reliability of the water supply source in terms of water availability as a source for meeting future demand, and does not take into consideration the various technical aspects as precondition for meeting water demand in the future e.g., appropriateness and efficiency of water intake structure, treatment plant capacity and water supply distribution network.

4.1 Current situation of water demand and supply (2015)

Before any scenario was developed the current water supply and demands for various demand sites was analysed. The Analysis also take into consideration the monthly average available water in relation to supply requirement for 2015. Figure 4.1 shows annual water requirement for different water uses in the catchment. It is evident from the figure that, Reservoirs for irrigation water requirement and riverine irrigation gave a total agricultural annual water requirement of 125 million cubic meters in the catchment while Urban and rural, and livestock water requirement are 20 million cubic meters and 23 million cubic meters, respectively. The total water requirement for the demand sites in the catchment is 148 million cubic meters.

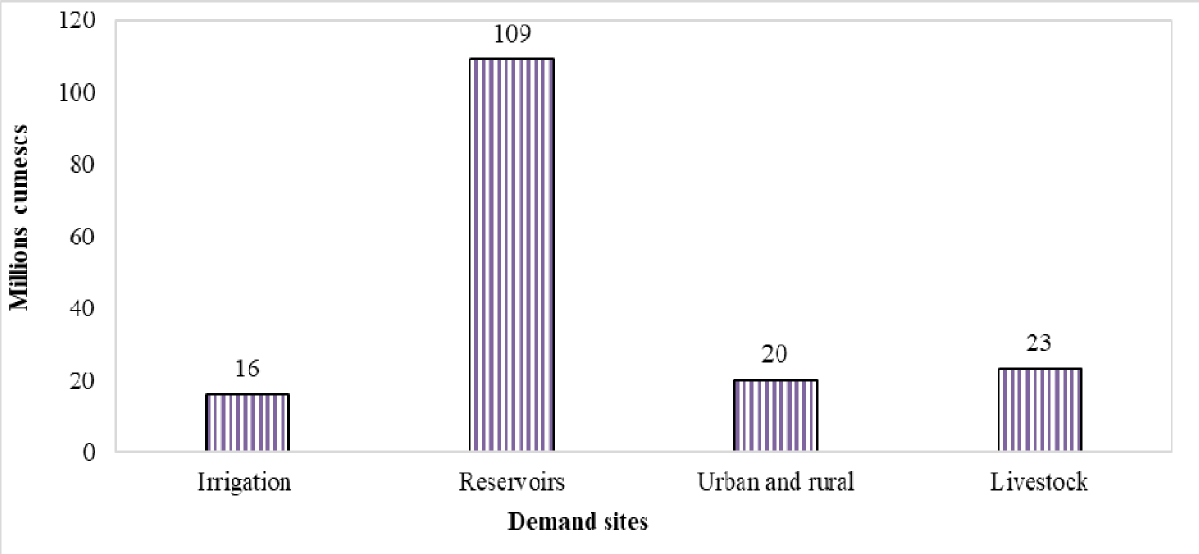

Figure 4.1: Annual supply requirement for the demand sites (2015).

Under the Urban and rural water requirement (supply requirement for Tamale and environs), Domestic water requirement has the highest value (17.1 million cubic meters) and Institutional water requirement being the least (1.3 million cubic meters). Water requirement for Commercial is 1.4 million cubic meters. Figure 4.2 show annual water requirement for Tamale Metropolis and environs.

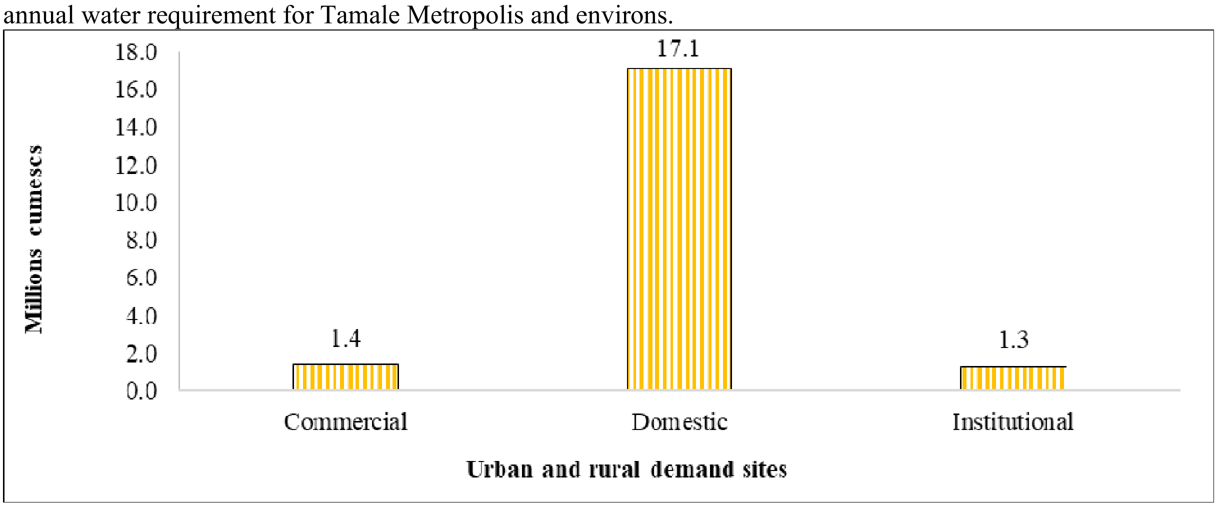

Figure 4.2: Annual supply requirement for Tamale and environs for 2015.

The current monthly average water requirement among multiple water users however indicates that, the current water use is low compared to the current average supply available as observed in the figure 4.3. Exclusion of loses, remaining stream flow is the flow after meeting supply requirement for various demand sites. There is no much difference between available streamflow and the remaining stream flow under the current situation except of the period from June to August where there is a slight drop. This is the period of the year when reservoirs are filled. There is a drop of 2% of the total streamflow for the current situation.

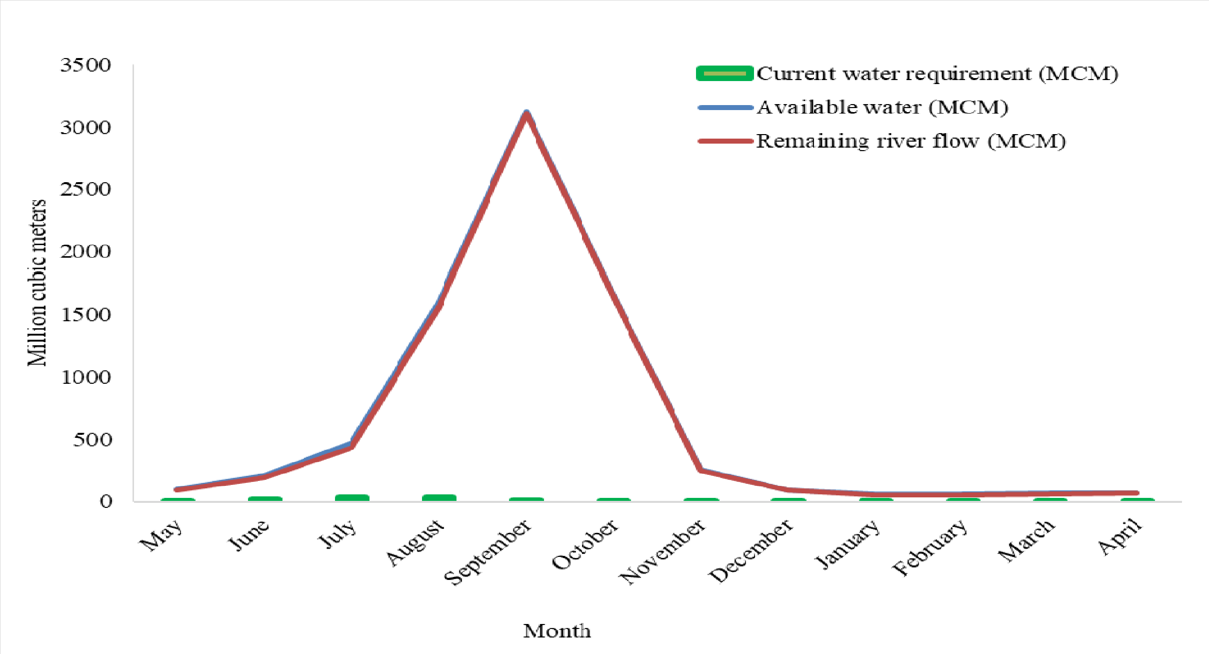

Figure 4.3: Current Monthly average inflow and outflow

Water supply requirement is fully met under the current situation. Reliability is therefore 100% for demand sites as shown below (figure 4.4).

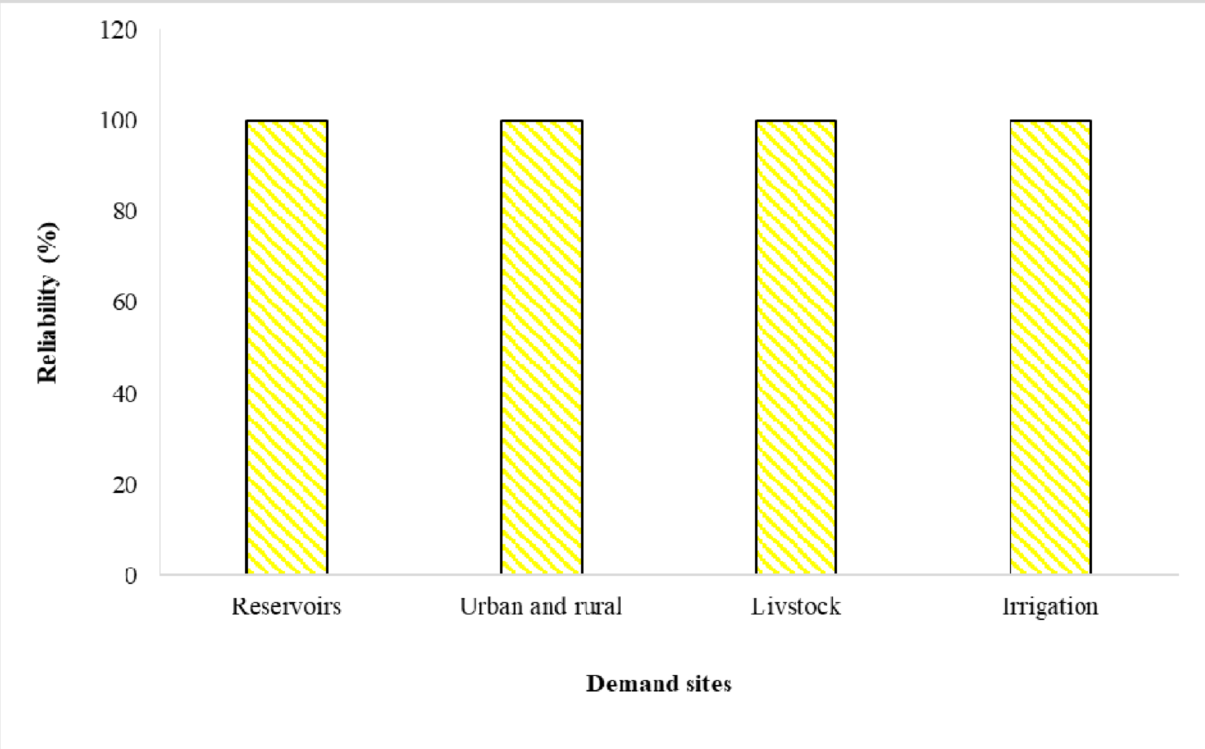

Figure 4.4: Reliability for the Demand Sites for 2015

4.2 Baseline (Reference) scenario

Reference or baseline scenario simulates likely evolution of the system without intervention. In this scenario, current annual growth rate of 2.9 % and 2.5 % was applied to human and livestock population, respectively that are likely to occur and not depend on any intervention and policy change. The analysis was also based on the current growth rate of irrigation. The irrigated area in the upstream of the catchments has been growing at a rate of 5.6 % since 2005 (Ofosu, 2011). Water demand and supply from 2015 to 2035 of all water users was modelled. The Model generated the water requirements for the next 20 years.

4.2.1 Supply Requirement

It is shown from the figure 4.5 that, the water supply requirement for Tamale City and the environs (urban and rural water requirement) estimated at 20 million cubic meters in the base year (2015) increased to 33 million cubic meters in 2035. The increase in supply requirements for the city and rural is due to increasing population growth. Moreover, the water requirements for irrigation and small reservoirs increase from 16-31 and 4-6 Million cubic meters, respectively; which can be attributed to expansion of the irrigated area. Likewise, the demand for livestock is increasing due to increasing livestock population. However, water requirement for large reservoirs remains constant throughout the study period.

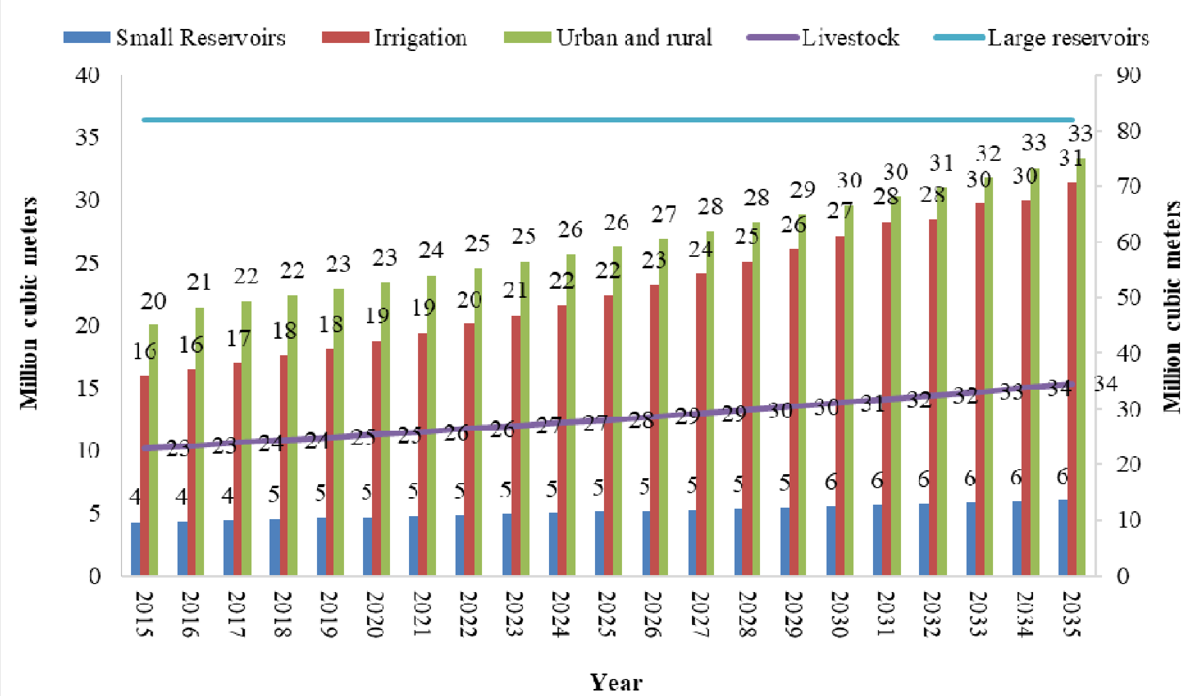

Figure 4.5: Water Supply Requirements for demand sites in Million Cubic Meters

4.2.2 Supply delivered

The supply requirement and supply delivered to the various demand sites as shown in the figure 4.6 do not vary; the supply delivered is 100 % for all demand sites in all years under Reference scenario. Hence there is no shortage of supply. That is, unmet demand has zero (0) value for 2015 to 2035 all for the demand sites.

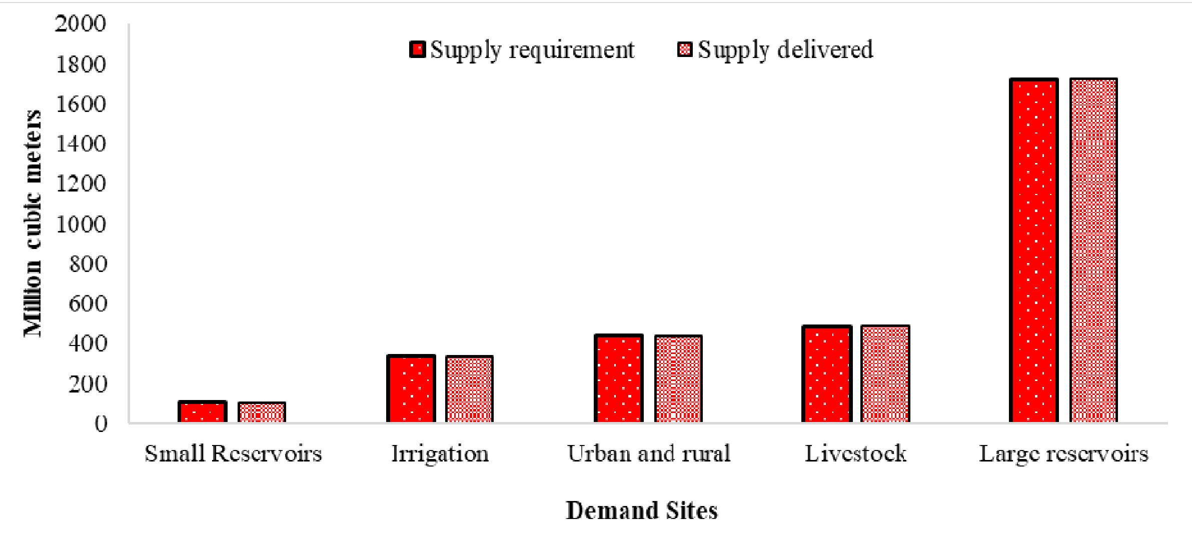

Figure 4.6: Water Supply delivered to the demand sites (Million cubic meters).

4.3 Scenario 1: High population and Socio-economic growth

In this scenario, the twin pressure of rapid urbanisation resulting in high population growth, and socio-economic growth have been considered. The scenario is created in order to foresee the future increase in water demand impact on the availability of water resource supplied to Tamale city and the environs considering population and socio-economic growth.

4.3.1 Supply Requirement

Figure 4.7 below show water requirement projection base on both scenarios, high population and socio-economic growth, and reference scenario. Water requirement for the case of high population and socio-economic growth gives much higher value in 2035 compared to reference scenario; which can be attributed to the couple effect of high population growth rate and increase in annual water use rate resulting from socio-economic development. The total annual water requirement for Scenario 1 is observed to be 1,488 million cubic meters in 2035 compared to The Reference scenario which has a total annual water requirement of 240 million cubic meter.

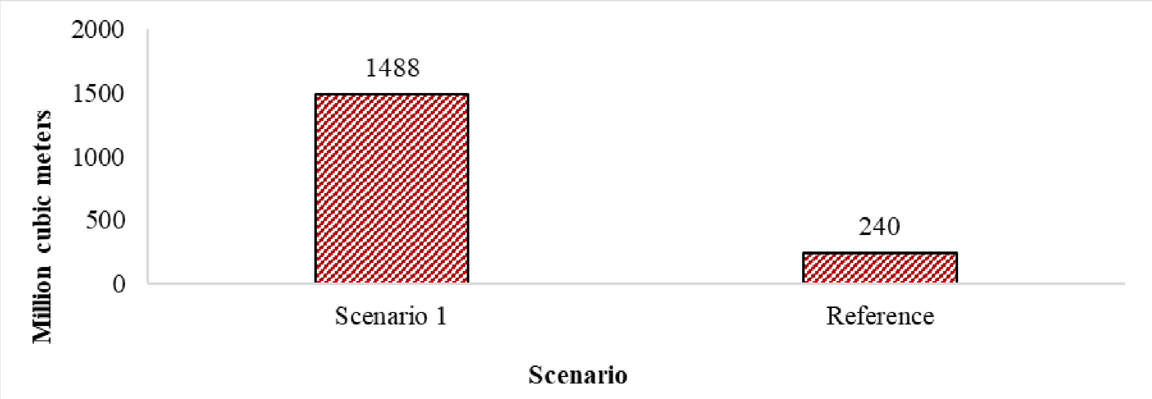

Figure 4.7: Water supply requirement Projection for 2035 for Nawuni Catchment under Scenario 1 and Reference scenario

4.3.2 Supply delivered and un-met demand

For irrigation, livestock, small and large reservoirs' demand sites, the supply requirement and supply delivered are the same while supply requirement and supply delivered for urban and rural demand site varies. That is, supply delivered 100% in all years for all demand sites exception of urban and rural demand site where in some years, there is shortage of supply i.e., supply delivered is less than 100%. This indicates that under the scenario of high population and socio-economic growth, there will be shortage of water supply within the projected period (2015-2035). Figure 4.8 show total supply requirement and supply delivered for next 20 years.

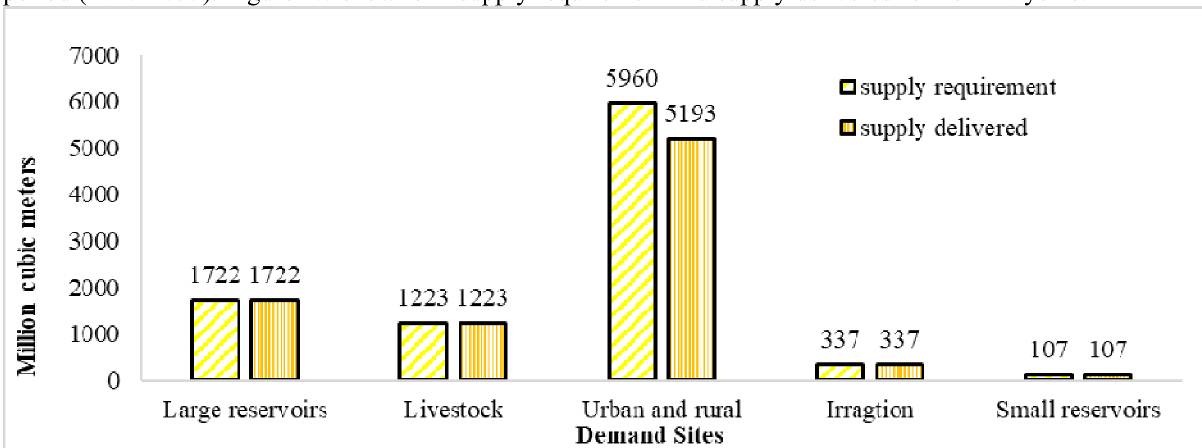

Figure 4.8: Total supply requirement projection for 2035 in million cubic meters

Figure 4.9 indicate the results of unmet demands for the urban and rural water demand site from 2015-2035, generated from the WEAP model. From the results generated it is observed that urban and rural demand site has an un-met demand of 4.1 million cubic meters for the year of 2032 which increased to 229 million cubic meters in 2035.

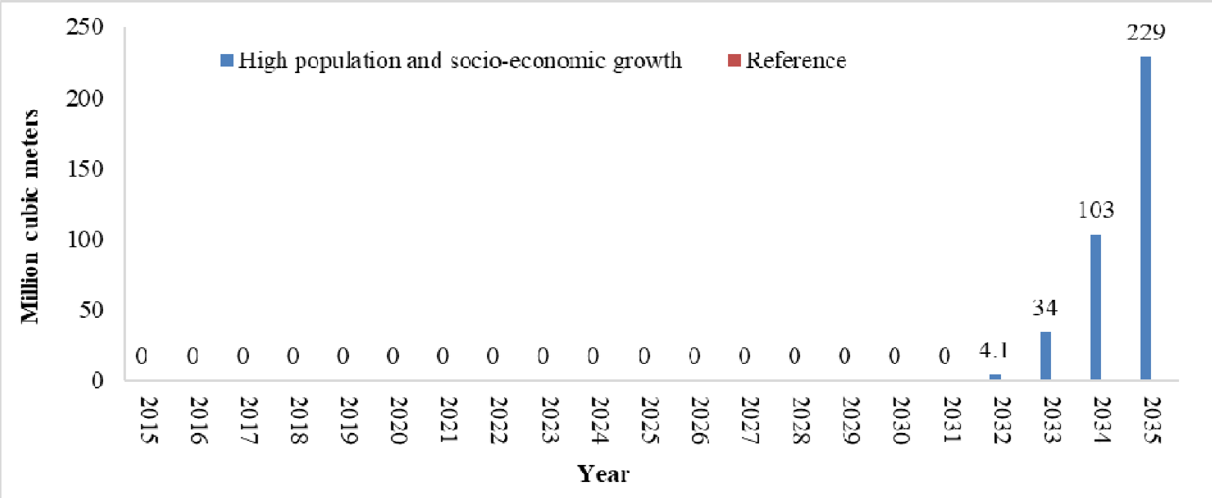

Figure 4.9: Un-met Water Demands (Millions Cubic Meters)

4.3.3 Supply reliability

Exception of Urban and rural demand site, all demand sites are fully fulfilled i.e., reliability is 100% as shown in Figure 4.10. For urban and rural water demand site, reliability is 88% i.e., 12% of the demand is not fulfilled.

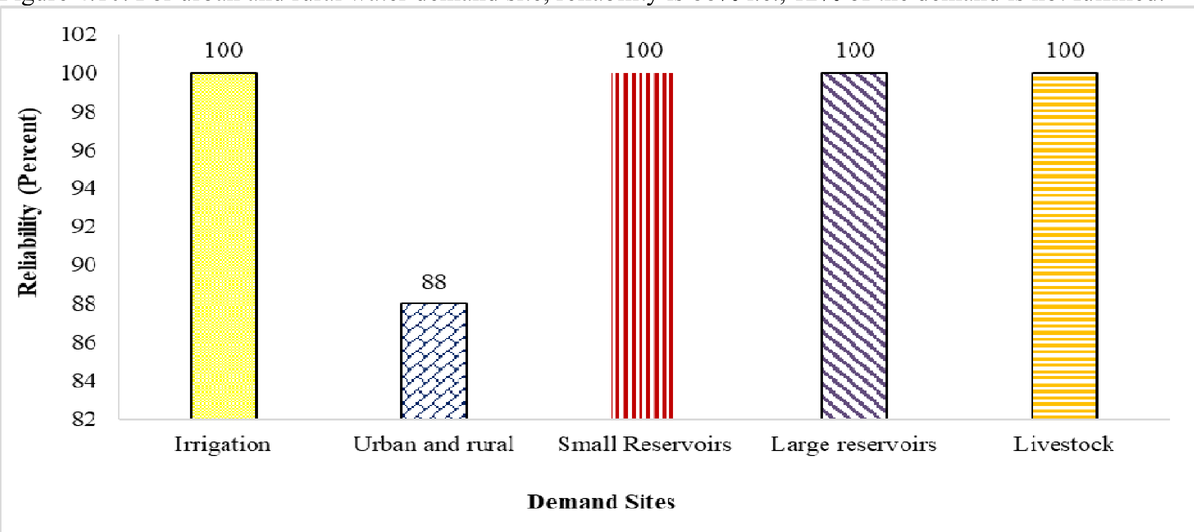

Figure 4.10: Reliability for the Demand Sites

4.3.4 Impact on available water

The impact of scenario 1 on the available water for supply is shown in Figure 4.11. It is indicated that there is a reduction in the streamflow throughout the year. The highest percentage (38%) drop occurs in January and February. This is the period of the year where there is high demand for water. There is a total annual drop of 7% of the streamflow for this scenario. It also indicated in the figure that; the remaining river flow is lower than supply requirement during the dry season (December to April). This implies that, there will be serious water shortages in the future if water supply requirement increases beyond what is predicted in this scenario. High population and socio-economic growth have impact on sustainable water supply from Nawuni River for Tamale and environs in the future especially during the dry season as shown in the Figure.

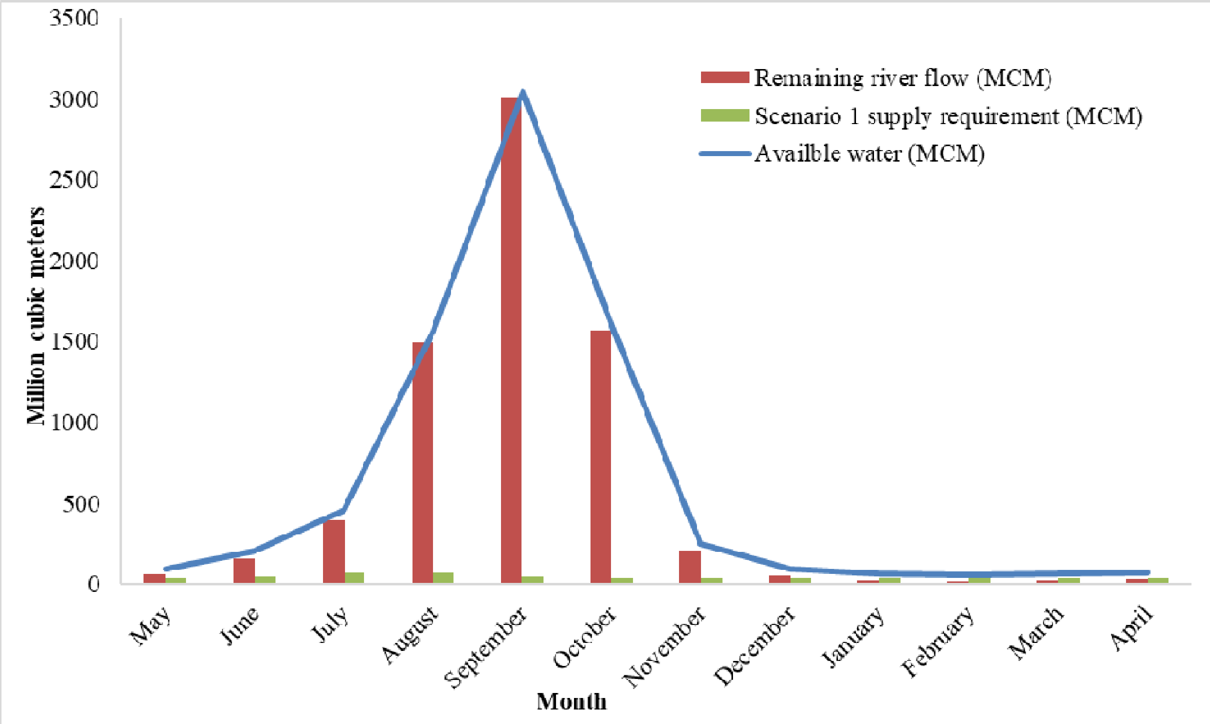

Figure 4.11: Monthly average inflow and outflow under scenario 1 (2015-2035)

4.4 Scenario 2: Competing water uses upstream

Due to the competition for water needs and the upstream - downstream effects of growing water uses, this scenario seek to assess the potential impact of intensifying water uses upstream and the possible future effects for sustainable water supply for Tamale Metropolis and the environs. This scenario is added to assess the implication of future development upstream.

4.4.1 Supply Requirement

The water requirement generated for the demand sites for next 20 years is shown in Figure 4.12. It is observed that water supply requirement for irrigation under scenario 2 increased from 130 to 205 million cubic meters from 2015 to 2035 compare to reference scenario which increases from 130 to 174 million cubic meters. The total supply requirement of the reference scenario is 3142 million cubic meters which increased to 3547 under scenario 2 representing 11% increase in upstream water use.

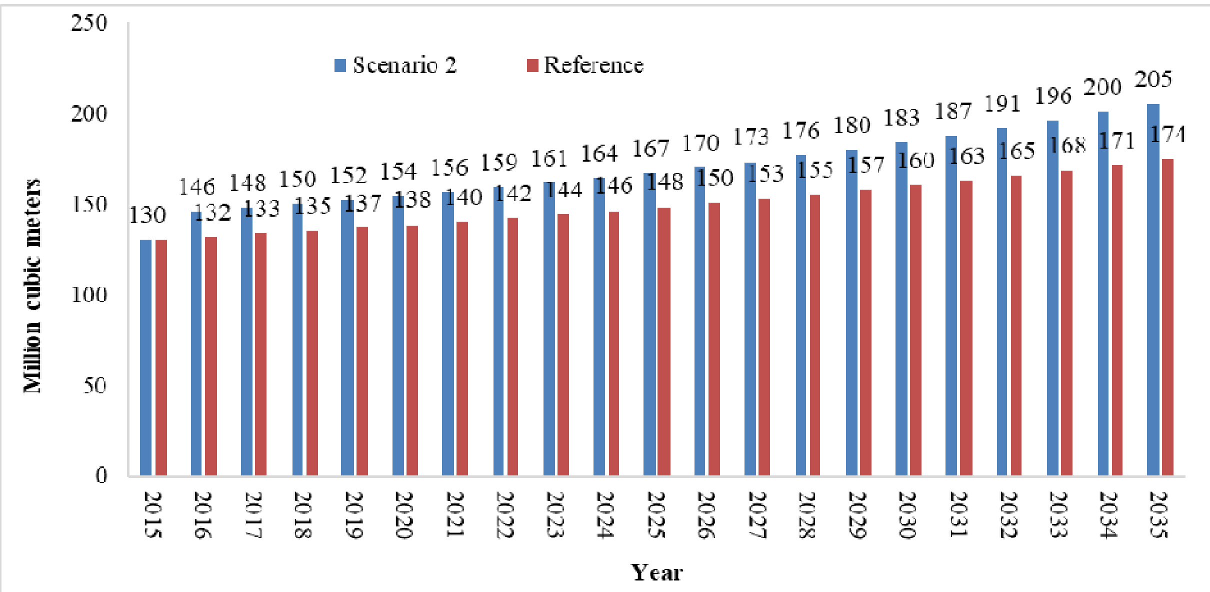

Figure 4.12: Supply requirement Projection from 2015-2035 for Nawuni Catchment under Reference Scenario and Scenario 2: Intensifying upstream water use

Figure 4.12: Total Supply requirement Projection from 2015-2035 for Nawuni Catchment under Reference Scenario and Scenario 2: Intensifying upstream water use

4.4.2 Supply delivered

It is observed from the figure 4.13 that, the supply requirement and supply delivered to the various demand sites do not vary under this scenario; the supply delivered is 100 % for all demand sites in all years. Hence, zero is observed from 2015 to 2035 for unmet demand for all the demand sites, therefore, supply requirement is fulfilled for all demand sites despite intensifying upstream water uses.

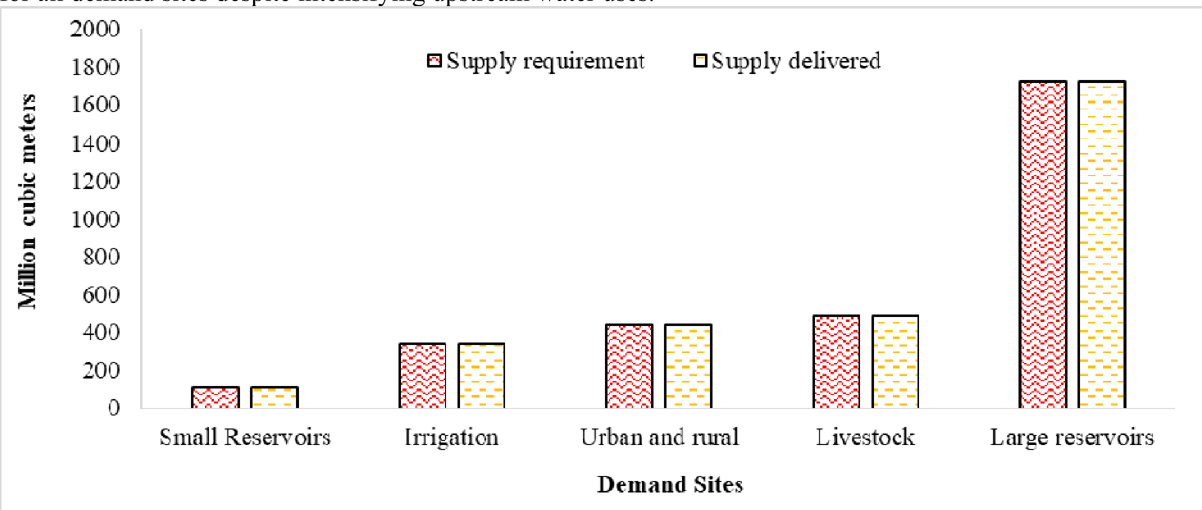

Figure 4.13: Water Supply delivered to demand sites (Million cubic meters).

4.4.3 Impact on available water

The total water abstraction by all demand sites combined from the river could be said to have insignificant effects on the available water flow in the river. As shown in figure 4.14 there is slight reduction in the streamflow throughout the season which represent 2.5% drop of the total annual streamflow under scenario 2: intensifying upstream water use. It is also evident in the figure that, the supply requirement is lower compare to remaining river flow for all months. This implies under normal climate condition of scenario 2: intensifying upstream water use as described has no significant impact on the river flow for downstream water use. Hence has no impact on the availability of water supplied to Tamale metropolis and environs.

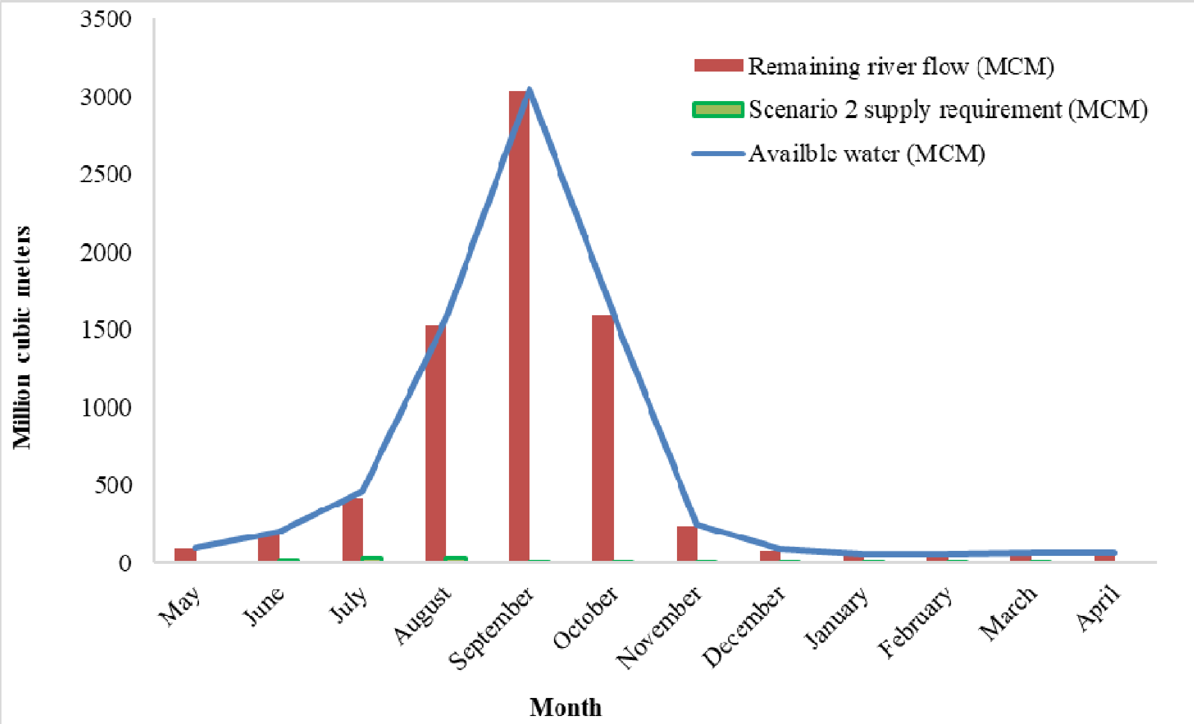

Figure 4.14: Monthly average inflow and outflow at scenario 2 (2015-2035)

4.5 Extended dry climate

The previous scenarios only varied demand and not supply. These scenarios are created to assess impact of drought under each scenario: Reference scenario, Scenario 1: High population and socio-economic growth and Scenario 2: intensifying water use upstream so that to evaluate the impact towards water demand and supply. From the results, where extended dry climate occurred under scenario 2 (intensifying water use upstream) and Reference Scenario, water demand is said to be fully fulfilled. However, when Extended dry climate occurred under Scenario 1: High population and Socio-economic growth, there is shortage of water supply starting from 2030 as showed in Table 4.1. The values for unmet demand are much higher when Extended Dry Climate occurred under Scenario 1.

It is also observed in the table that, there is zero Unmet Demand in 2031, even though there is a rise in demand for water resulting from high population and socio-economic growth. This is because 2031 is a Very Wet year where there is an increased in precipitation and headflow to the river which mitigate the increased in demand for water. On the other hand, in the Dry and Very dry years (e.g., 2030, 2032 and 2034) the High population and Socio-economic growth is aggravated by the reduced precipitation and headflow in the river in these years which is indicated by higher values of unmet demand as showed in Table 4.1. This therefore indicated that, unmet demand increased substantially with High population and Socio-economic growth rate for Extended Dry climate.

Table 4.1: Projection of Unmet Demand from 2015-2035 of Scenario 1 and unmet demand of Scenario 1 under Extended Dry Climate Sequence

Years	**…28**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Scenario 1	0	0	0	0	4.1	34	103	229
Scenario 1 under Dry Climate	0	0	10	0	54	66	287	342

4.5.1 Impact on available water

The impact of Extended Dry Climate on the streamflow occurring under Scenario 1, Scenario 2 and Reference scenario is shown on the figure 4.15. There is reduction in available total annual streamflow by 10 %, 13 % and 10.14 % for Reference Scenario, Scenario 1, and Scenario 2, respectively, inherited from Extended Dry Climate. The impact of the above scenarios (Reference Scenario, Scenario 1, and Scenario 2) on the available streamflow is therefore exacerbated by extended dry climate. This means Extended Dry Climate has impact on water demand and supply in the future particularly when it is occurred under high demand resulting from population growth and socio-economic development.

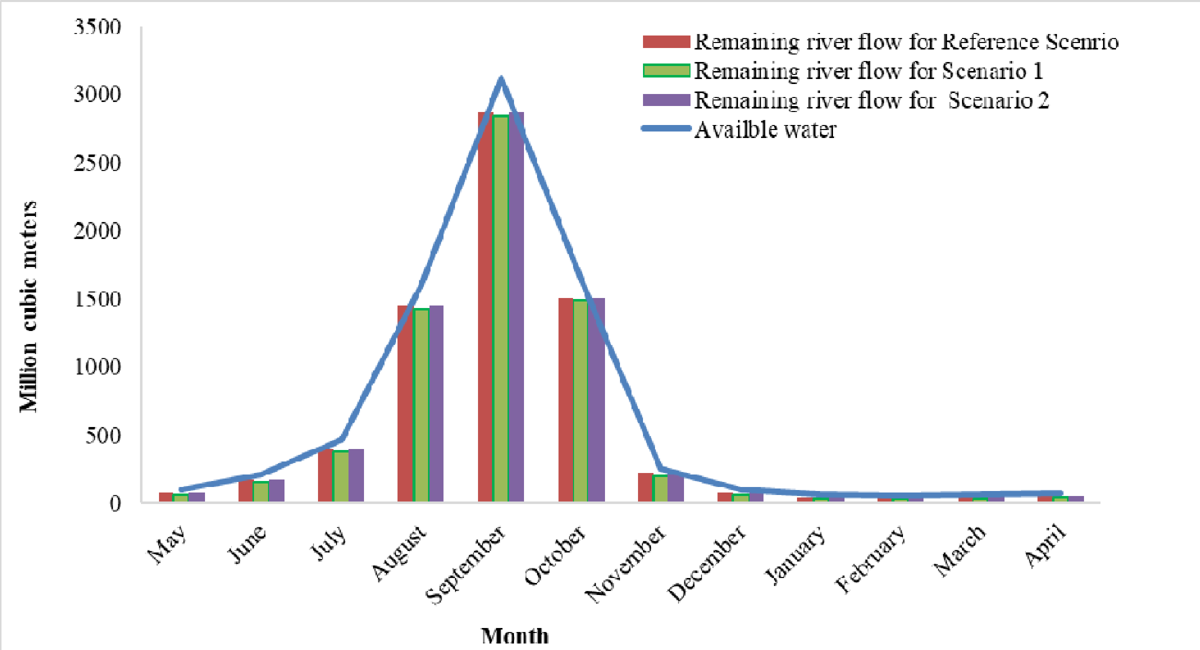

Figure 4.15: Monthly average inflow and outflow at scenario 1, 2 and Reference Scenario for Extended Dry Climate (2015-2035)

5. Conclusion

Based on the current situation of water demand, the available water is sufficient to meet demand. Besides, where the potential impact of intensifying water uses upstream and the possible future implications was assessed, the results showed that, intensifying upstream water use as projected in the study does not have impact on the downstream water availability for sustainable water supply to Tamale Metropolis and the environs.

However, the assessment made on the scenario of rapid population and socio-economic growth, revealed that, water demand will outstrip raw water supply by 2029. And this is predicted to be exacerbated by Extended Dry Climate. Therefore, investigation of possible options of water storage reservoir becomes indispensable in order to mitigate the effects of extended dry season.

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