SURFACE WATER DEMAND AND SUPPLY OF GABORONE CITY AND SURROUNDING AREAS: RESPONSE TO CLIMATE CHANGE AND POPULATION INCREASE

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ABSTRACT

The adequate supply of the ever-increasing demand of fresh water continues to be a challenge in parts of the globe. This challenge has been aggravated due to increasing population and climate change. The anticipation for better lifestyles and improved water supply has resulted in an increase in migration from rural settlements leading to an increase in the populations of many cities globally. This study therefore investigates the variability and trends in the surface water demand and supply of the city of Gaborone and surrounding areas in response to population growth and climate change using the Water Evaluation and Planning (WEAP) model for future scenarios. The study includes analysis of population trends, water production and consumption rates, hydrological of the study area as well as projected climate data at a high spatial resolution of 1 km^2. The current General Circulation (GCM) or Regional Climate (RCM) models are not able provide such data. Therefore, the climate data for existing GCMs is statistically downscaled using the high resolution Worldclim data to spatial resolution of 1 km^2 and bias corrected against Global Climatology Precipitation Center (GPCC) precipitation. The GCM data for the mid-range Concentration Representative Pathways (RCP4.5) and high emission RCP 8.5 future scenarios of Coupled Model Inter-comparison Project Phase 5 (CMIP5) are employed in the study. Under both RCP4.5 and RCP8.5 scenarios, the reservoir inflow indicates that the level of reservoirs at Foresthill, Diremogolo, Gabane hill, Oodi hill and Mabutswe will be reduced during 2081-2097 period. The unmet water demand of the whole study area will be 52.5 million m^3 in 2050 as compared to 1490 million m^3 in 2100 under RCP 8.5 climate and high population growth scenarios. However, the unmet demand under RCP4.5 climate and high population growth scenarios will be 51.14 million m^3 in 2050 as compared to 1450 million m^3 in 2100. On the other hand, the unmet water demand will be reduced by as much as 50% under both scenarios if low population growth rate of 2.2% is assumed. As an option of water management, increasing water loss reduction by 3% every year could drastically reduce the unmet water demand.

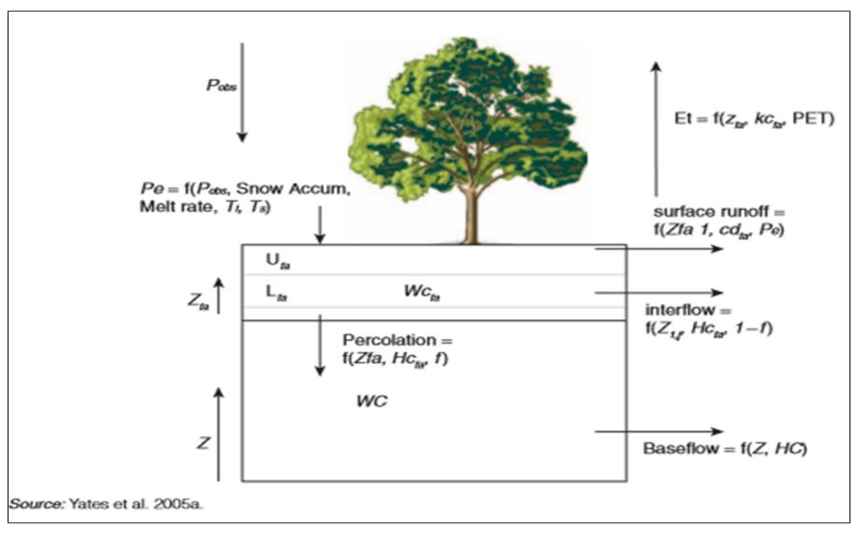
Introduction and objectives

The prolonged surface water stress experienced in Botswana as a whole has been one of the major problems faced by the government of Botswana. Owing to its flat topography, low rainfall amounts, high seepage generally cause by sandy soils, and high evaporation rates, Botswana has few surface water resources. This inhibits the sufficient supply of water to many of its areas. High water loss rates lead to reductions in the levels of water resources which also contribute to higher water supply deficits. As an urban area Gaborone is also prone to facing such water supply deficits due to its rapidly increasing population which eventually over flows to its neighbouring sub-cities. The general objective of this study is to investigate the surface water demand and supply prospects of the city of Gaborone and its neighbouring villages through the application of the Water Evaluation And Planning (WEAP) model using scenarios of population growth trends and climate change.

Materials and Methods

Methods WEAP: Water Evaluation And Planning model

Soil moisture method



Weap then integrates the results of the two balance equations to come up with

Water supply

- through precipitation

Water demand

- natural processes (evapotranspiration)

$$Sw\frac{dzj}{dt} = P_e(t) - PET(t)_{kc,f}\ (t)\left(\frac{5z_{i,j-2}\ z_1^2}{3}\right) - P_e(t)z^{\frac{LAI}{2}} - f_jK_{z,j}Z_1^2 - (1-f_j)k_{z,j}Z_{i,j}^2 \quad (1)$$

- **For every reservoir, water balances are calculated as:**

$$s_j^t - S_j^{t-1} = Q_{in.j}^t - Q_{out,j}^t - L_j^t \quad (2)$$

- **Water demand for each demand node, was calculated as follows:**

$$Demand\ Annual = \sum_{Br}(Total\ activity\ level_{Br}' \times Water\ use\ rate_{Br}'' \times \ldots) \quad (3)$$

- **For every water demand there is a supply requirement**

$$Supply\ requirements = (Demand_{Dsm} \times (1 - Reuse\ rate_{Dsm}) \times (1 - DSM\ savings_{Ds}))/(1 - Loss\ rate_{Ds}) \quad (4)$$

$$Demand\ Site\ Inflows_{Ds} = \sum_{Src} TransmissionLink\ Outflow_{Src,Ds} \quad (5)$$

- **Demand site inflow should be equal to its supply requirement unless;**

-there are water shortages due to hydrological, physical, contractual or other constraints **i.e.;**

if

$$Demand\ site\ Inflows_{Ds} \geq Supply\ requirements_{Ds} \quad (6)$$

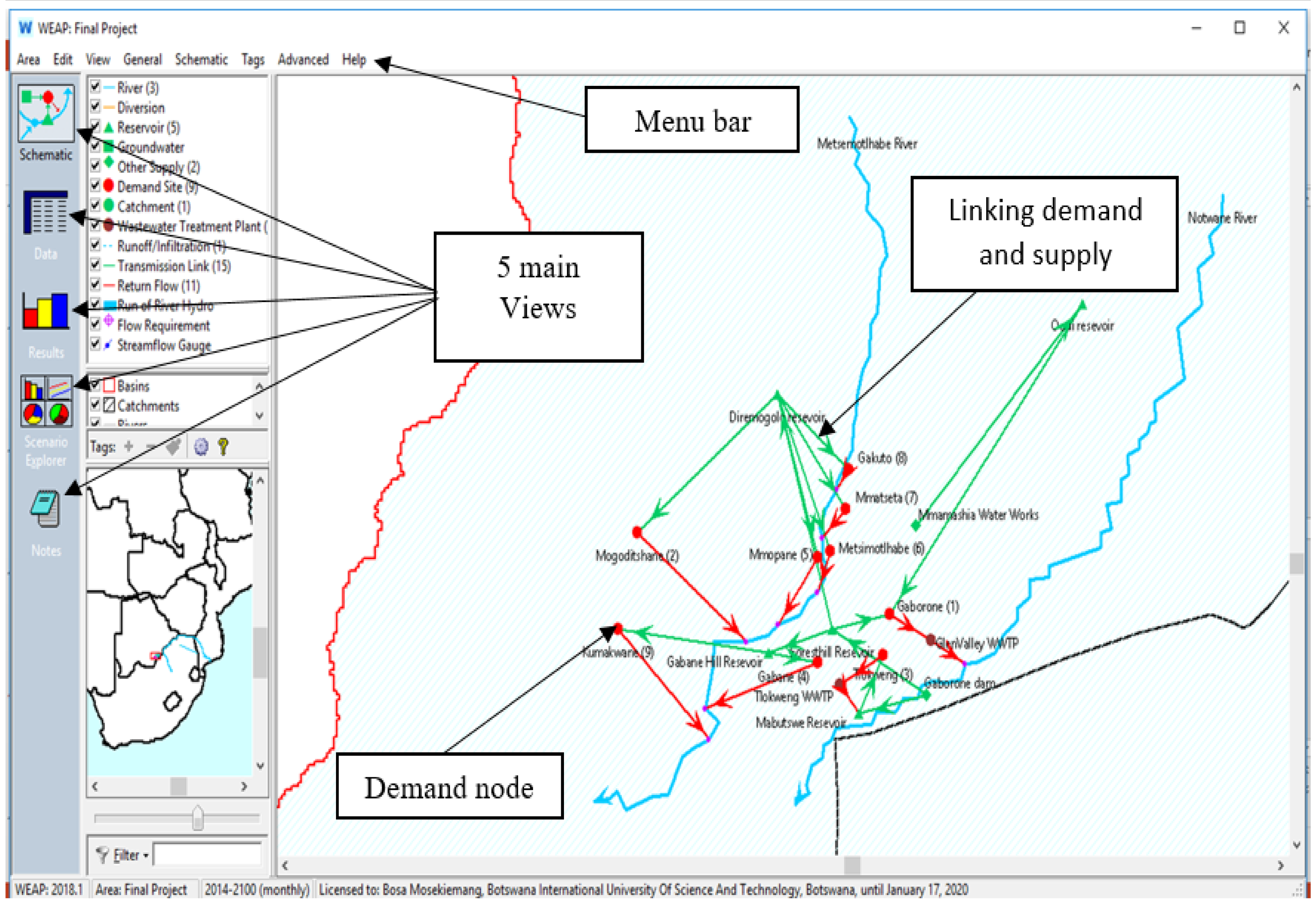
Adequate supply

and if;

$$Demand\ site\ Inflows_{Ds} < Supply\ requirements_{Ds} \quad (7)$$

Inadequate supply(unmet demand)

Experimental design



RESULTS AND ANALYSIS

Model calibration

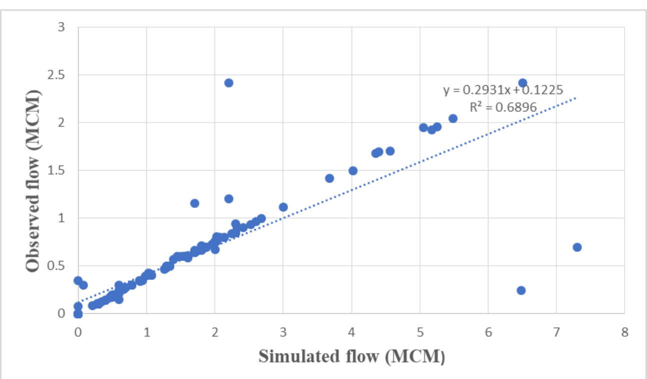


Fig 1 mean observed and simulated flow of Notwane River.

Fig 1 Shows model calibration results. The WEAP model has been tested on a monthly and yearly time step basis. The model performance was evaluated using statistical parameters such as the mean error (ME), mean square error (MSE) and the model coefficient of efficiency (EF). Observed stream flows recorded at the Notwane gauging station are compared to the simulated flows produced by the model. Results show that simulated flow at Notwane gauge station with the observed flow gives an EF of 0.91. Result shows that the simulated flows match the observed values relatively well.

Impacts of population increase on water demand

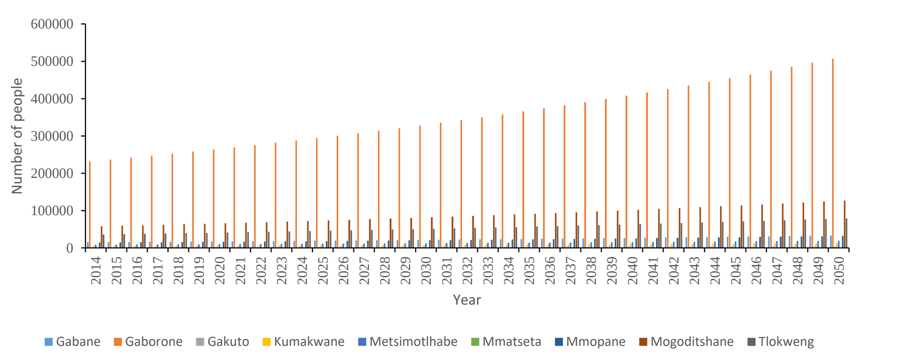


Fig 2(a) : Projected population growths of Gaborone and surrounding areas at 2.2% low pop growth rate (2014-2050)

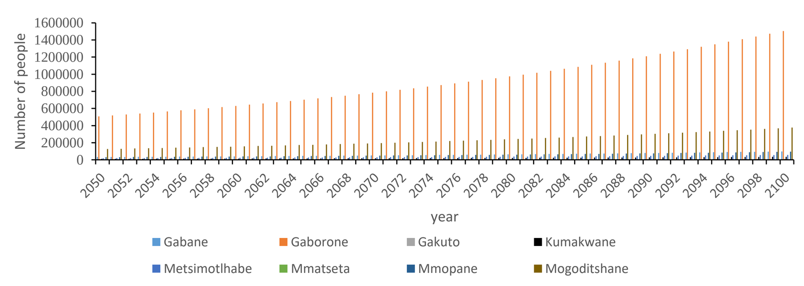


Fig 2(b) : Projected population growths of Gaborone and surrounding areas at 2.2 % low pop growth rate (2051-2100)

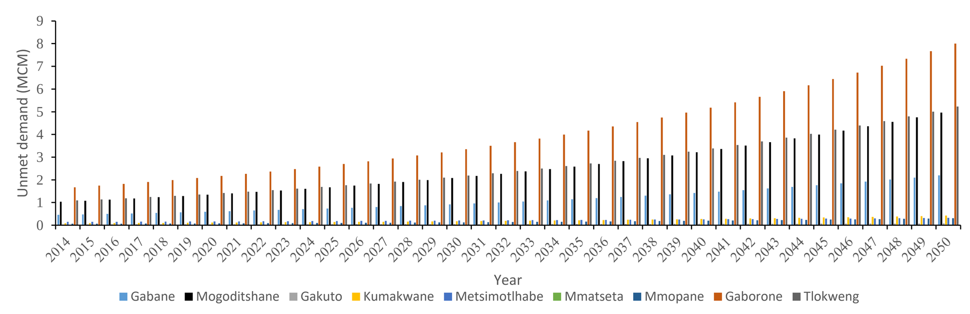


Fig 3(a): projected unmet water demands at 2.2% low pop growth rate (2014-2050

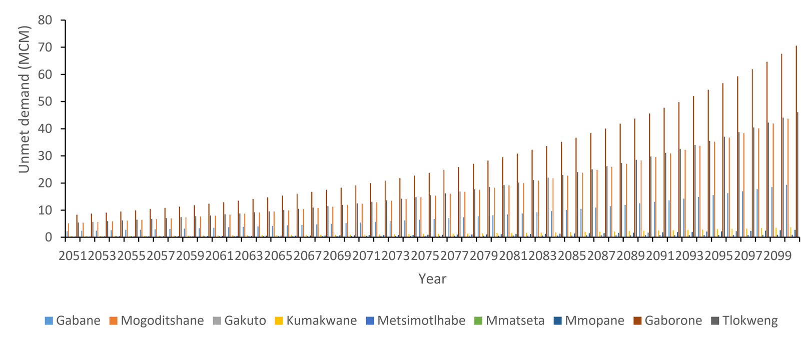


Fig 3(b): projected unmet water demands at low pop growth rate 2.2% (2051-2100)

Impacts of climate change on water supply

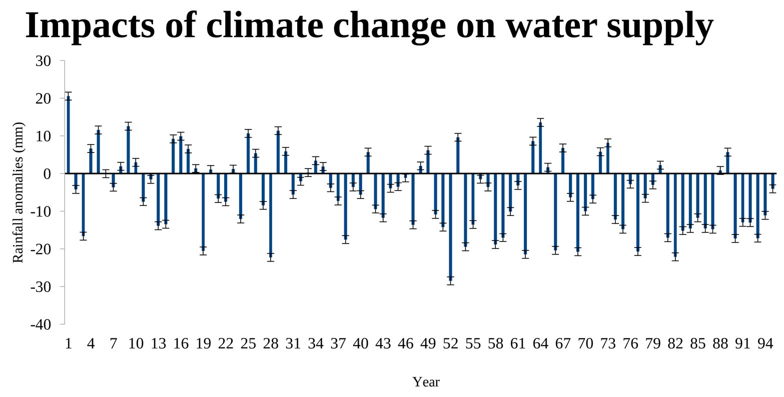


Fig 4(a):RCP 4.5 anomalies from the mean (1975-2005)

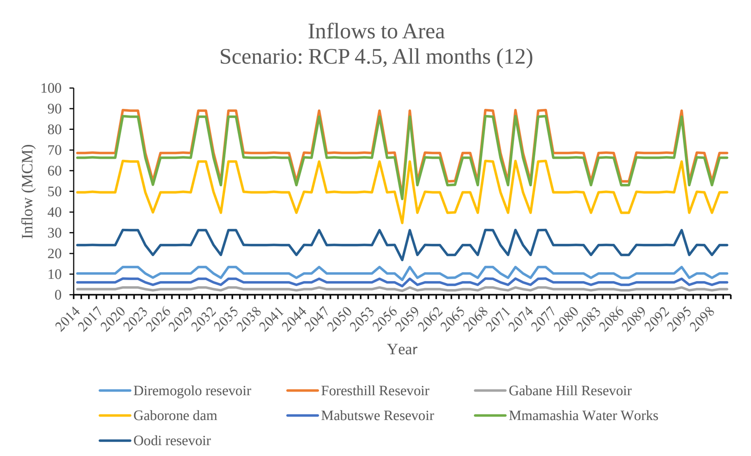


Fig 4(b): Rcp 4.5 future reservoir inflows

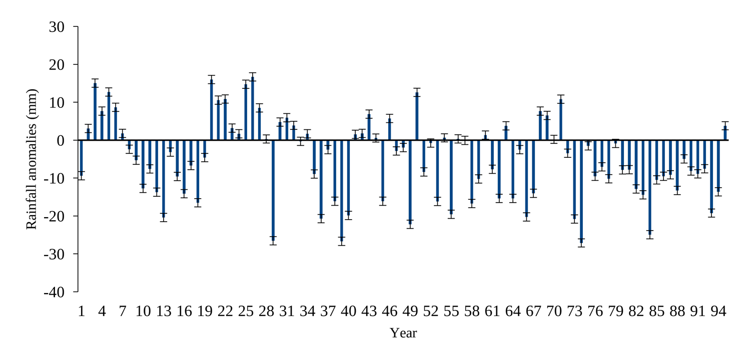


Fig 5(a): Rcp 8.5 anomalies from the mean (1975-2005)

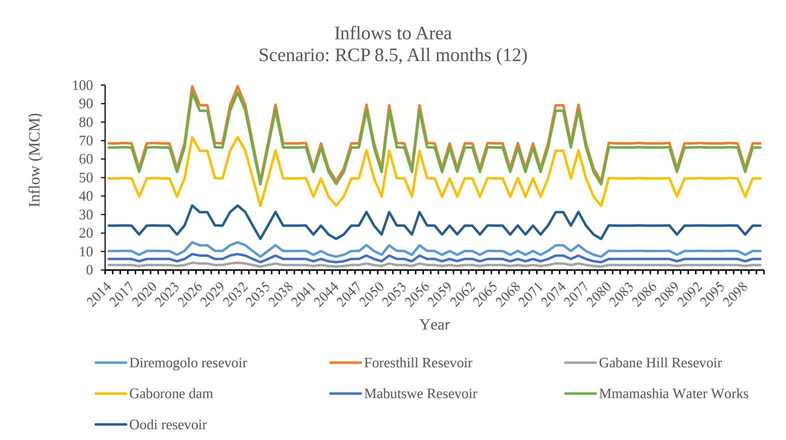


Fig 5(b): Rcp 8.5 future reservoir inflows

Gaborone dam future inflows: 2050: 49.58 MCM , 2070: 39.66 **2094: 64.45** , 2100: 49.58 **RCP 4.5 low pop growth rate**

Gaborone dam future inflows: 2050: 39.66 MCM , 2070: 49.58 **2094: 49.58** , 2100: 49.56 **RCP 8.5 low pop growth rate**

Low population growth rate : 2.2%

Pop in 2014,2050 and 2100 = 231k ,506k and 1.5 M (for Gaborone)

Unmet demand in 2014,2050, and 2100 = 0.45 MCM,7.76 MCM, and 68MCM

- The more the population, the more the anticipation for fresh water.

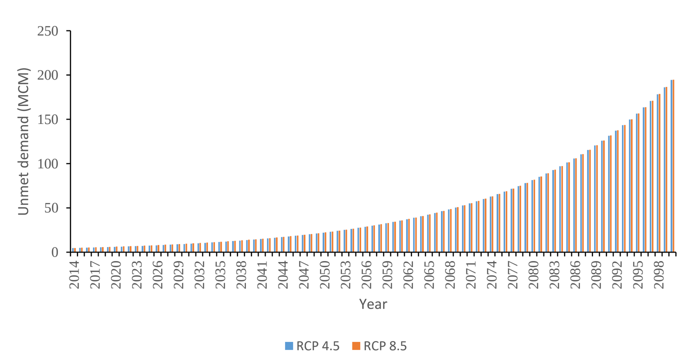


Fig 6(a): unmet demands Rcp 4.5 &8.5 at low pop growth rate

- Unmet demand RCP 4.5 @ Low pop growth rate 2050:22.07 MCM 2100:194 MCM
- Unmet demand RCP 8.5 @ Low pop growth rate 2050:22.37 MCM 2100:197.7 MCM

Fig 6(b): unmet demands Rcp 4.5 & 8.5 high

- RCP4.5 climate with high population (3.4%) scenario indicates that the unmet demand= 51.14 MCM in 2050 as compared to 1450 MCM in 2100
- RCP8.5 climate with high population scenario unmet demand= 52.5 MCM in 2050 as compared to 1490 MCM in 2100.

Possible interventions to the projected water supply deficit

- **Water loss reduction by 3% every year via technology advance**

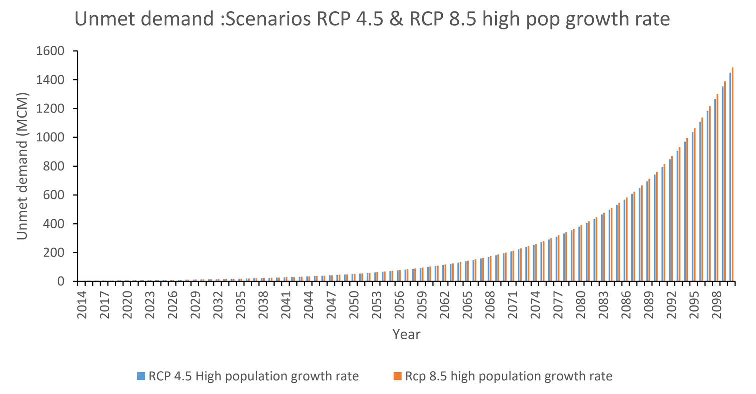


Fig 7 (a) RCP 8.5 &4.5 unmet demands before loss

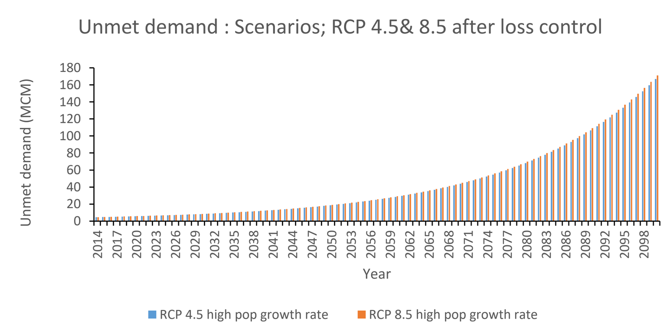


Fig 7 (b) RCP 8.5 &4.5 unmet demands after loss control

- Rcp 4.5 Unmet demand before loss control: 1450 M ,After loss control: 166 MCM
  Rcp 8.5 Unmet demand before loss control: 1490 MCM ,After loss control: 171 MCM

CONCLUSION

- Increase in population leads to increased unmet water demand hence water management strategies should be drawn and taken into consideration on time.
- For the study area, the RCP 8.5 scenario appeared to be drier than the RCP 4.5 scenario leading to higher unmet water demand in the RCP 8.5 climate scenario as to RCP 4.5 which means the government should encourage low green house gas emissions.
- water re-use and proper infrastructural maintenance are some of the management options that can be used to reduce the future unmet water demands as well as saving it . However cost analysis should be done before implementation.

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