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Impacts of climate change on crop and irrigation water requirement in the Savannah regions of Ghana

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ABSTRACT

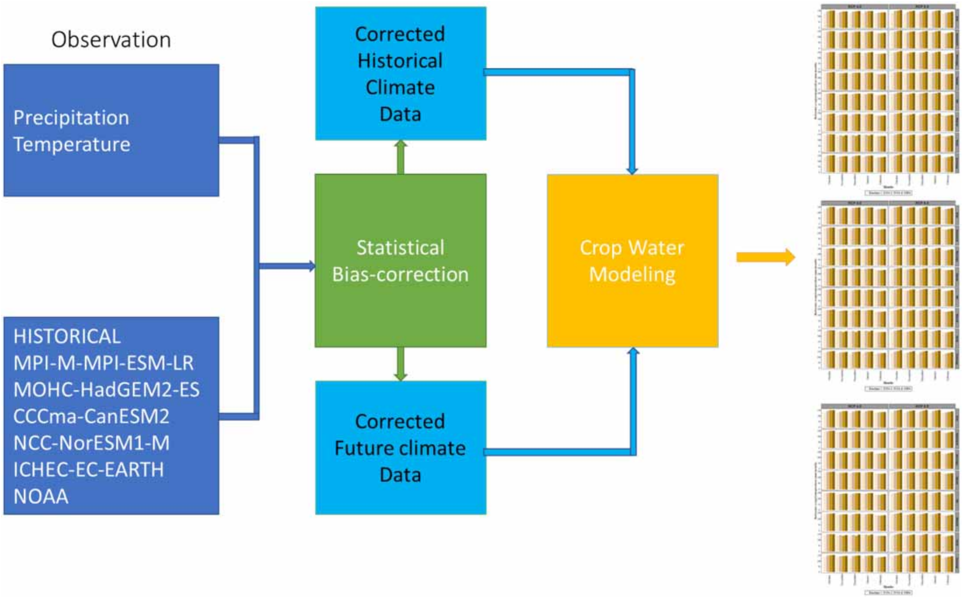
Irrigation is important for food security, however, water requirements for sustainable irrigation may be affected by climate change. The study analysed water requirements of two commonly cultivated crops in the dry season in the Ghanaian Savannah regions under baseline and future periods. Crop water requirement (CWR) and crop irrigation requirement (CIR) were lowest in baseline periods and increased in the 2020s, 2050s, and 2080s for RCP 4.5 and RCP 8.5 at all locations. CIR was higher for tomato as compared to onions for most locations. Seasonal changes in the CWR ranged from 2–9, 3–12, and 3–12% and 2–8 3–12% and 5–18% for the 2020s, 2050s and 2080s under RCP 4.5 and RCP 8.5, respectively, for both the crops. Bole and Zuarungu recorded highest increases in CWR for tomato, whereas the least change was observed at Yendi for onions. Changes in seasonal CIR ranged from 3–19, 2–21, and 6–22%, respectively, for the 2020s, 2050s and 2080s for RCP 4.5. Under RCP 8.5, changes in seasonal CIR ranged from 3–23, 5–23, and 6–27% were observed for the 2020s, 2050s, and 2080s, respectively. Highest increases in CIR were noticed at Bole and Zuarungu for tomato, whereas the least change was observed at Wenchi for onions. Findings of the study support zero hunger and climate action, goals 2 and 13 of the Sustainable Development Goals (SDGs).

Key words: climate change, crop water requirement, irrigation water requirement, Savannah zone

HIGHLIGHTS

- The study analysed water requirements of two commonly cultivated crops in the dry season in the Savannah regions of Ghana.
- Crop and irrigation water requirements were generally lowest in baseline periods and increased in the 2020s, 2050s, and 2080s under RCP 4.5 and RCP 8.5.
- Highest increases in irrigation requirement were noticed at Bole and Zuarungu for tomato, whereas the least change was observed at Wenchi for onions.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Many locations in sub-Saharan Africa are classified as being arid or semi-arid. In these areas, finding water for domestic purposes, livestock watering, and agricultural purposes is a major challenge, especially during the dry season. This is mainly due to the low rainfall amounts received as well as the high temperatures in these areas. These result in water shortages and scarcities which lead to drought and famine (Eilander 2013).

In Ghana, these challenges are not uncommon in the zone demarcated under the Savannah Accelerated Development Authority (SADA). The SADA zone of Ghana is generally classified as having a semi-arid climate and is thus plagued with almost all the challenges that are characteristic of such climates. Water resources in the zone are often stressed due to multiple uses and the resultant high demand. In the SADA zone of Ghana, like the rest of the country, agriculture remains the major economic activity for the inhabitants. However, agriculture is rain-fed and thus largely determined by the climate. Given this, agricultural activities tend to be mostly limited to about only 4 months within the year since the Savannah regions are characterized by a unimodal rainfall pattern. To combat this, farmers have often relied on water from hand-dug wells, dams, and storage reservoirs. However, these systems do not last the entire dry season and tend to dry up before the rains begin.

Increasing temperature and rates of evaporation resulting from changing climate are expected to exacerbate this situation, leading to prolonged drought and water scarcity (Kasei 2009; Hijioka *et al.* 2014). The questions that arise in the light of these occurrences are how sustainable agriculture will be and the possible measures that can enhance food security in the region. Improved irrigation practices, the choice of the right crops, and the proper management of water resources are the proposed measures to help combat the situation. This requires an understanding of how evapotranspiration rates are going to change and the impacts it will have on water demands by plants, especially those that are grown in the dry season, and the subsequent irrigation requirements to plan for the judicious use of the limited water resources as well as improve and increase the storage facilities to enhance the capture and store rainfall during the rainy season.

However, information about the exact changes that are expected is limited in this area. This makes it difficult in planning and implements subventions. Irrigation schemes that have been attempted have not considered the possible variations in climate at different locations within the zone as well as the water demands for the different crops cultivated.

Therefore, an understanding of the amounts of water required by different crops under particular climatic conditions will be required for the planning of irrigation schemes and practical design of water-saving and management systems (Rao *et al.* 2011). Despite these imminent challenges facing agriculture in the Savannah zone of Ghana, the zone is known to be a large producer of tomatoes and onions which are often exported to the southern parts of Ghana (Clottey *et al.* 2009).

With these in mind, this study analysed the water requirement of two crops cultivated in the dry season, tomato and onion, for the present climate and the future periods, the 2020s, 2050s, and 2080s, under the RCP 4.5 and RCP 8.5 scenarios. These analyses were carried out individually for eight climate stations in the semi-arid (Savannah zone) of Ghana. The findings from this study are aimed at providing the necessary information for the sustainable planning and design of interventions as well as the right policies to safeguard agricultural activities in the Savannah zone of Ghana.

2. MATERIALS AND METHODS

2.1. Study area

The study was carried out in the northern part of Ghana (8 °00′N–11 °00′N and longitudes 0 °01′E–3 °00′W) (Figure 1). It is the area designated as the Savannah zone of Ghana by the SADA of Ghana. The area covers the Upper West, Upper East, Northeast, Northern, Savannah, parts of Bono East, and Oti regions. The zone was established in 2010 by an act of Parliament (SADA Act 825) to develop a strategy to bridge the North–South divide in terms of economic growth and the standard of living of Ghanaians.

The zone is characterized by a variable climate, both spatially and temporally. The climate in the study area is primarily semi-arid in the northern parts, semi-humid in the central regions, and then humid in the southern parts (Liebe *et al.* 2009). The area falls within three ecological zones: Guinean Savannah, Sudanian Savannah, and the Sudano-Sahelian, which cover just a little section (Kranjac-Berisavljevic *et al.* 1999). The Guinea Savannah receives a yearly rainfall average of about 1,000–1,300 mm, and this rainfall occurs in two periods (bi-modal). This first period runs from March to June, while the second one is from September to November (Kranjac-Berisavljevic *et al.* 1999; Ghansah *et al.* 2018). The Sudanian Savannah zone also receives an annual rainfall of about 900–11,000 mm, and it occurs during July, August, and September, while the Sudano-Sahelian zone receives an annual average rainfall of about 500–900 mm between June and October

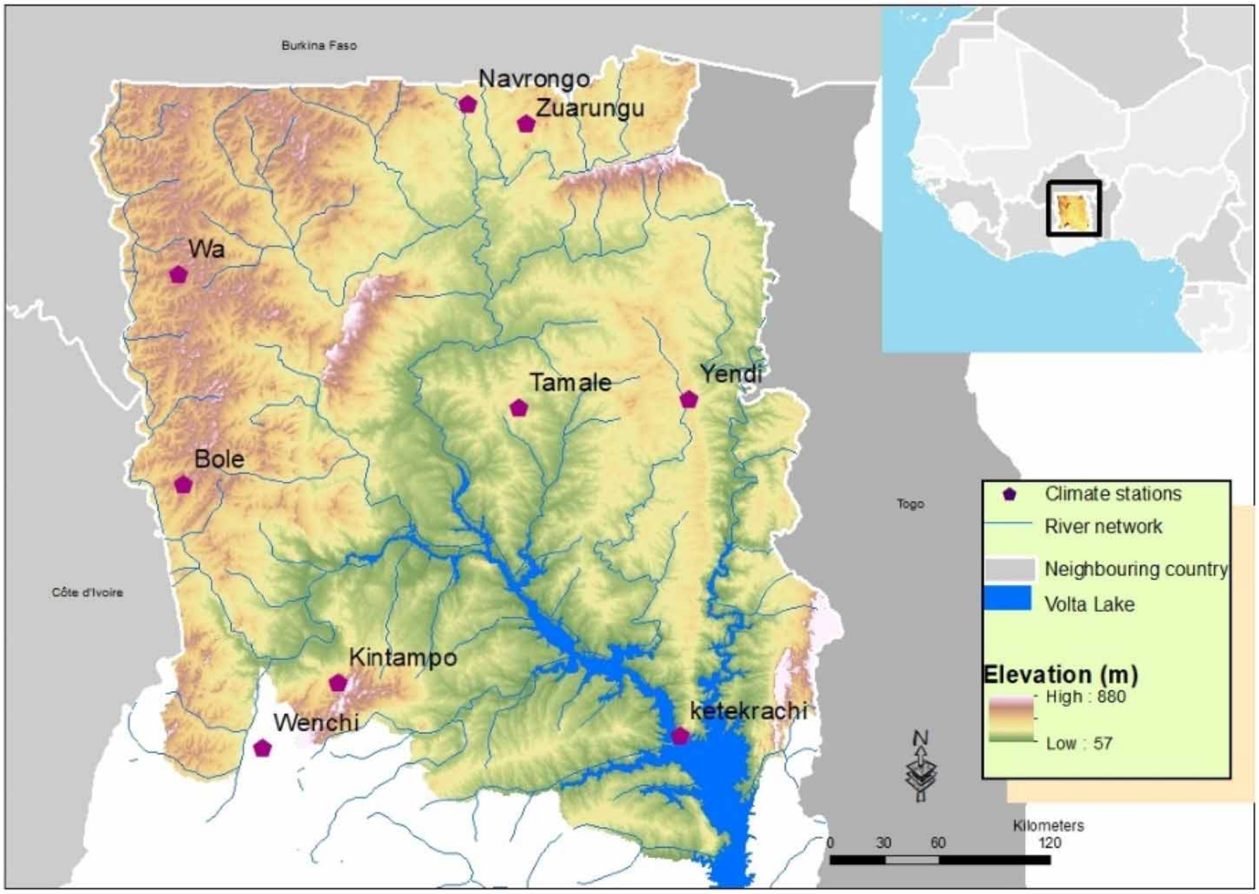


Figure 1 | Location of climate stations in the Savannah zone of Ghana.

(Kranjac-Berisavljevic *et al.* 1999; Ghansah *et al.* 2018). Thus, the area is said to have a mono-modal rainy season (Kranjac-Berisavljevic *et al.* 1999). Rainfall is unpredictable with significant variations (concerning onset, quantity, and coverage) from one season to another and with significant disparities between successive seasons, in terms of the time of onset, extent, and quantity (Obuobie 2008; Ghansah *et al.* 2018). The mean monthly temperature is in the range of 27 and 36 °C in the northern part and 24 and 34 °C in the southern part.

A large percentage of the inhabitants in the SADA zone are peasant farmers living in scattered rural communities (Darko 2018). The farmers are highly defenceless against upsets due to the limited augmentation of their income sources (World Bank 2011). Thus, any slight variation in the climates often results in poverty, hunger, and high competition for the limited available resources (Mul *et al.* 2015).

2.2. Baseline data

A 30-year (1975–2005) observed rainfall and temperature obtained from the Ghana Meteorological Agency (GMet) was used as the baseline data for this study. The data were from eight climate stations (Table 1) within the Savannah zone. These observed data were used to calculate reference evapotranspiration rates for the baseline period and then subsequently used to estimate monthly and seasonal crop water requirement (CWR) and crop irrigation requirement (CIR) for the baseline period. Water requirements were calculated for each of the individual climate stations based on the indication of variations in CWRs based on the location by Agodzo *et al.* (2003); therefore, the analysis was carried out individually for each of the eight climate stations.

2.3. Climate change data

For the simulation of future climate, regional climate models (RCMs) participating in the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Jones *et al.* 2011) were used. The RCM simulations utilized were daily precipitation and temperature values from 2006 to 2096. Inherent biases that are usually a characteristic of such models were corrected using the CMhyd tool. The distribution mapping bias correction method was used. The multi-model average (ensemble mean) of six RCM–Global Climate Models (GCMs) (Table 2) was used in the analysis. The ensemble mean of these RCMs was used

Table 1 | Description of climate stations used in the study (latitude and longitudes in decimal degrees and elevation in metres)

Climate station	Longitude	Latitude	Elevation
Bole	−2.49	9.03	297.00
Kete-Krachi	−0.05	7.80	85.00
Kintampo	−1.73	8.06	339.00
Tamale	−0.84	9.24	196.00
Wa	−2.51	10.06	305.00
Wenchi	−2.10	7.74	304.00
Zuarungu	−0.81	10.80	213.00
Navrongo	−1.09	10.89	196.00
Yendi	−0.01	9.45	252.00

Table 2 | Details of RCMs used in this study

Model	Driving GCM	RCM institute	Adopted Id
REMO	MPI-M-MPI-ESM-LR	CSC	REMO-MPI
RCA4	MOHC-HadGEM2-ES	SMHI	RCA4-HadGEM2
RCA4	CCCma-CanESM2	SMHI	RCA4-CanESM2
HIRHAM	NCC-NorESM1-M	DMI	HIRAM-NorESM1
RACMO	ICHEC-EC-EARTH	KNMI	RACMO-EARTH
RCA4	NOAA	NOAA	RCA4-NOAA

in the climate projection because it is known to have a higher accuracy than the individual RCMs in most cases (Paeth *et al.* 2011; Nikulin *et al.* 2012). The ensemble mean was used to simulate mean monthly temperature and rainfall values for both RCPs 4.5 and 8.5 for the 2020s (2006–2035), 2050s (2036–2065), and 2080s (2066–2096) for each climate station.

2.4. Calculation of reference evapotranspiration, CWR, and CIR

The procedures for calculating CWR and CIR were based on methodologies presented in the Food and Agriculture Organization (FAO) paper (Allen *et al.* 1998). The reference evapotranspiration refers to the amount of water that is lost by crops through the process of evapotranspiration, whereas the CWR represents the amount of water that is required to meet the evapotranspiration needs of that particular crop (Mhashu 2007).

To calculate the reference evapotranspiration, the FAO Blaney-Cradle Hargreaves (Hargreaves & Samani 1985) method was employed. This method is widely used in regions with limited data and also has proven to be effective in semi-arid and dry sub-humid regions (Demirtas *et al.* 2007; Fooladmand 2011). It only requires the mean temperature and sunshine hours together with elevation data as inputs:

$$\mathrm{ET}_0 = \{a + b[P(0.46T + 8.13)]\}\left[1 + 0.1\left(\frac{\mathrm{Elev}}{1000}\right)\right] \quad (1)$$

where P is the mean daily percentage of total annual daytime hours for a given period and latitude; T is the mean daily temperature (°C); and a and b are correction factors.

CWRs were assumed to be the same as the actual evapotranspiration ($\mathrm{ET_c}$) because approximately 99% of the water uptake by crops is used to meet the evapotranspiration needs (Kariyama 2014). It was calculated based on the following equation (Allen *et al.* 1998):

$$\mathrm{CWR} = \mathrm{ET_c} = \mathrm{ET_0} * K_c. \quad (2)$$

where $\mathrm{ET_0}$ is the reference evapotranspiration (mm/day^{-1}) and K_c is the crop coefficient at a specific growth stage. It varies with the type of crop and the growth stage of that particular crop (i.e., initial stage, crop development, mid-season, and late season) (Chowdhury *et al.* 2016). The monthly K_c values for each crop type were obtained from Allen *et al.* (1998).

The initial, crop development, mid-season, and late season K_c values used in calculating the $\mathrm{ET_c}$ are presented in Tables 3 and 4 for tomatoes and onions. The K_c value for a particular month was obtained by determining the number of days in that month that covers a growth stage, divided by the number of days in that month (all months are assumed to have 30 days) and then multiplied by the K_c value of that growth stage. In situations where two or more growth stages are found in 1 month, the above process was repeated for each of the periods, and then the values are summed to derive the K_c for that month. The K_c values therein obtained are in mm/day. To obtain the monthly values, the K_c values were multiplied by the number of days in that month.

The K_c values of crops are known to be lowest at the initial developmental stages of crop and increase through the growth period, reaching their maximum value at the peak of the growth period. This is because at the initial stages, crop height and leaf areas are small; therefore, there is only a small amount of water uptake but as the crop grows to its peak, water use and losses increase (Sam-Amoah *et al.* 2013).

Table 3 | Crop data for tomato

Crop name: Tomato				
Planting date 01 October				
Harvest date 27 February				
Growth stage	Initial	Developmental	Mid-season	Late season
Length (days)	35	40	50	25
K_c value	0.6	0.75	1.15	0.8

Table 4 | Crop data for onion

Crop name: Onion				
Planting date 01 October				
Harvest date 27 February				
Growth stage	Initial	Developmental	Mid-season	Late season
Length (days)	20	30	60	40
K_c value	0.5	0.75	1.05	0.85

Effective rainfall (P_{eff}) is defined as the amount of rainfall available at the root level after the surface and sub-surface runoff, deep percolation, and evapotranspiration demands are met for consumption by the plant (Kariyama 2014). It was estimated based on the fixed percentage method. P_{eff} was estimated as 80% of the total rainfall based on Kariyama (2014).

The **CIR** was then estimated by deducting the effective precipitation from the CWR.

$$\mathrm{CIR} = \mathrm{CWR} - P_{\mathrm{eff}}. \tag{3}$$

The conceptual methodology used in this study is shown in Figure 2.

3. RESULTS

The results for the reference evapotranspiration (ET_0) of the baseline period together with future scenarios for each station are presented in Figure 3. The *X*-axis shows the duration of the cropping period which spans from October to February. The rate of evapotranspiration is projected to increase under RCP 4.5 and RCP 8.5 relative to the baseline period. The rate of evapotranspiration is expected to generally intensify from October to January with the reference evapotranspiration surging above 150 mm/month under both scenarios (see Figure 3). However, the intensity of evapotranspiration is expected to increase gradually in the 2020s and 2050s and become severe in the 2080s, especially under the worst-case scenario (RCP 8.5) (Figure 3). This shows that the demand for crop and irrigation requirements may increase in the mid- to far-future especially from October to December. The rate of evapotranspiration is directly associated with the prevailing temperatures at the selected stations. This is because evapotranspiration and temperature have a proportional relationship, whereas as temperature rises, evapotranspiration is also expected to increase. Therefore, evapotranspiration mimics the pattern of the prevailing temperature.

3.1. Monthly CWR (ET_c)

Figures 4 and 5 present the total CWR for tomato and onion during the growth period under RCPs 4.5 and 8.5.

Tomato is expected to increase from October to January and then drop in February by the end of the 21st century under both scenarios. However, the total CWR is expected to intensify in January under the RCPs 4.5 and 8.5. The highest demand for water from crops is expected to be observed in the 2050s and 2080s, especially under RCP 8.5. For instance, the total tomato water requirement under both scenarios is expected to rise above 150 mm/month (in all the stations except Yendi) in January in the 2050s and 2080s (see Figure 4). CWRs were lowest for the baseline period and then were observed to increase from the 2020s to the 2080s for most months barring February.

In terms of onion, the pattern is quite different from tomato (see Figure 5). The highest total CWR of more than 150 mm/month is expected to occur in December under both scenarios. The total CWR for onion is expected to surge gradually from October to December and start diminishing from January to February under RCPs 4.5 and 8.5. Similarly, the water requirement for onion is expected to be more intensive in the 2080s, especially under RCP 8.5 across all the stations (Figure 5). Generally, CWRs for both crops were lowest for the baseline period and then were observed to increase from the 2020s to the 2080s for most months barring February.

The mean monthly CWR for both crops corresponds with the reference evapotranspiration. This reveals a proportional relationship between evapotranspiration and the CWR for both crops. Thus, as the evapotranspiration increases, CWRs for both crops also increase. However, CWRs for both crops were observed to vary across the stations.

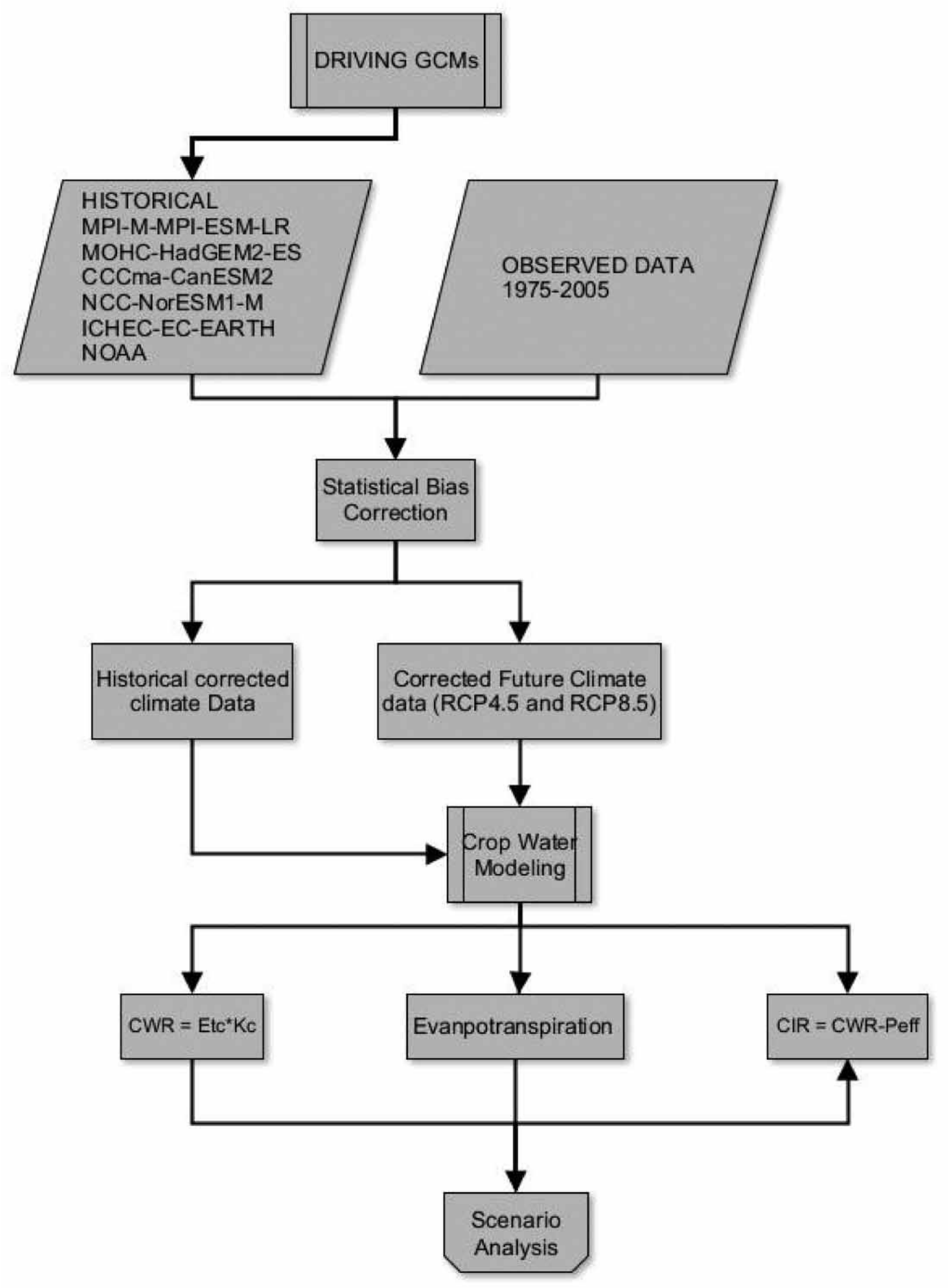


Figure 2 | Conceptual methodology adapted for this study.

3.2. Seasonal CWR

CWRs for the entire growth season varied between the two crops under RCPs 4.5 and 8.5 (Figure 6). The seasonal water requirement for both crops is expected to increase as the years progress (Figure 6). For instance, the seasonal water requirement for onion and tomato at Bole is expected to be more than 600 mm/growth period in the 2080s compared to about 550 mm/growth period in the 2020s.

However, the projected CWRs were relatively higher for RCP 8.5 as compared to RCP 4.5. Thus, as the radiative forcing increases from 4.5 to 8.5, seasonal crop water is also expected to surge except for Yendi where the water requirement in the 2050s was lower than that of the 2020s for both tomatoes and onions (see Figure 6). As seen earlier, evapotranspiration is

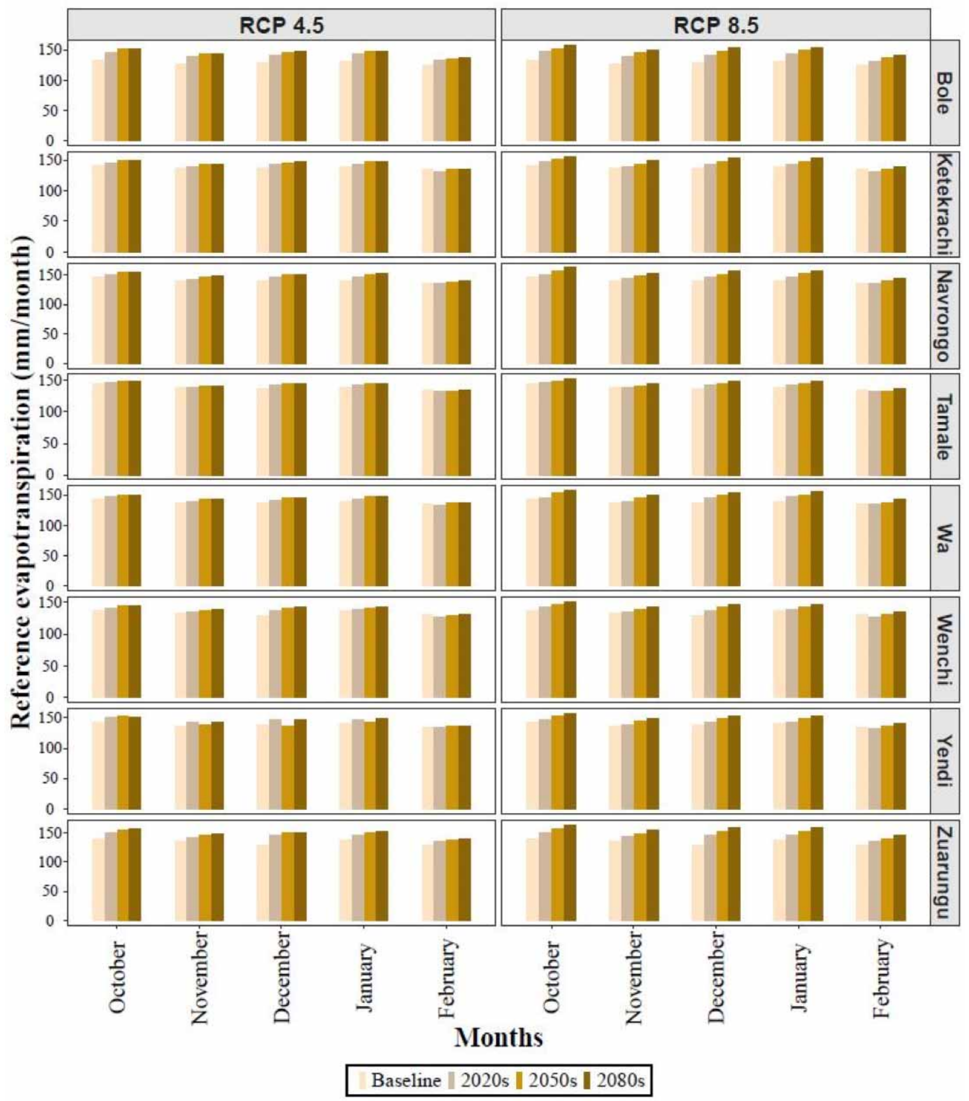


Figure 3 | Mean monthly reference evapotranspiration.

expected to be severe under the RCP 8.5 scenario compared to the RCP 4.5 scenario. This is expected to affect the seasonal crop requirement for both crops as a result leading to higher water requirements under the RCP 8.5 scenario. Increased surface temperatures are known to increase water loss by plants and from the soil. Moreover, Figure 5 reveals that the seasonal water requirement for tomatoes is expected to be slightly higher than for onions, especially in the worst-case scenario. This may be due to the differences in the morphology between tomato and onion. Onions can store more water compared to a tomato which depends solely on the amount of water available in the soil. Furthermore, the seasonal water requirement for stations in the Guinea Savannah region such as Bole, Navrongo, and Zuarungu is expected to be higher compared to Wenchi which is found in the transitional belt of Ghana where the temperature and evapotranspiration rates are relatively lower.

3.3. Change in CWR

Percentage changes in the CWRs for the two crops for the future periods as compared to the baseline period are presented in Figure 7. CWRs were observed to increase for all future periods at all climate locations. Considering the CWR for tomatoes, at Bole, water requirement was projected to increase by 9% in the 2020s under both RCP 4.5 and RCP 8.5. In the 2050s, the projections were 12 and 13%, respectively, under RCP 4.5 and RCP 8.5. A 13% increase was recorded in the 2080s under RCP 4.5, whereas for RCP 8.5, an 18% increase was observed. At Kete-Krachi, an approximately 2% increase was recorded

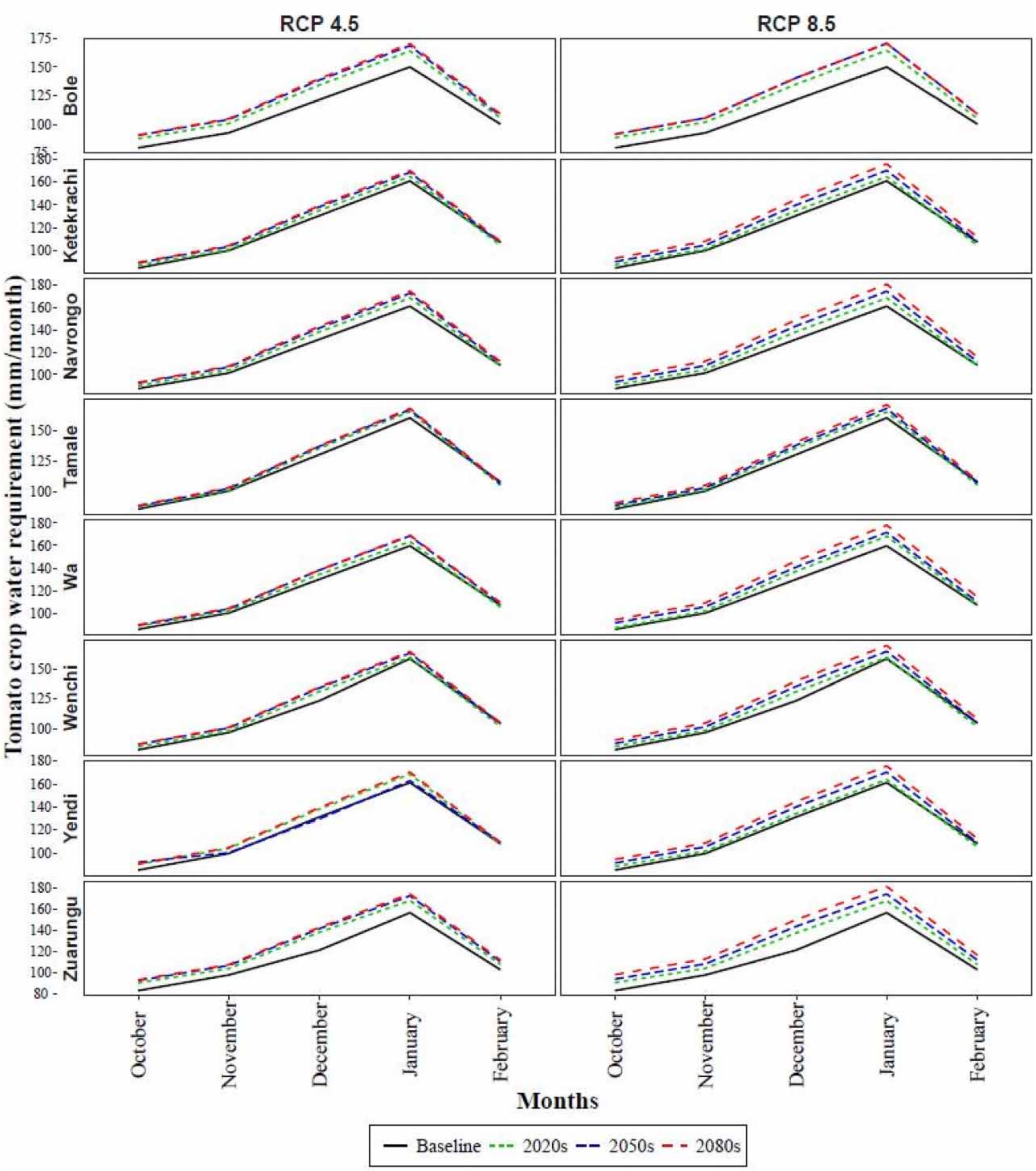


Figure 4 | Monthly crop water requirement for the baseline and future periods for tomato.

for both RCP 4.5 and RCP 8.5 in the 2020s, and then a 4 and 5% increase in the 2050s for RCP 4.5 and RCP 8.5, respectively. Finally, for the 2080s, a 5 and 9% increase in water requirements was projected under RCP 4.5 and RCP 8.5, respectively.

The changes recorded at Navrongo were a 2% increase in the 2020s under both RCP 4.5 and RCP 8.5. For the 2050s, approximately 5% was projected under RCP 4.5, while a 7% increase was projected under RCP 8.5. For the 2080s, the projected increases were 7% under RCP 4.5 and 11% under RCP 8.5. At Tamale, an approximately 2% increase in CWR was projected under both RCP 4.5 and RCP 8.5 for the 2020s and approximately 3% for both RCPs in the 2050s. Then for the 2080s, approximately 3 and 5% were projected for RCP 4.5 and RCP 8.5, respectively.

Projected increases at Wa were 2 and 3%, respectively, under RCP 4.5 and RCP 8.5 for the 2020s, 4 and 6% for the 2050s, and 5 and 10% for the 2080s under RCP 4.5 and RCP 8.5, respectively. An approximate increase of 2% was projected at Wenchi for the 2020s under both RCPs 4 and 5% for the 2050s, and 5 and 8% for the 2080s under RCP 4.5 and RCP 8.5,

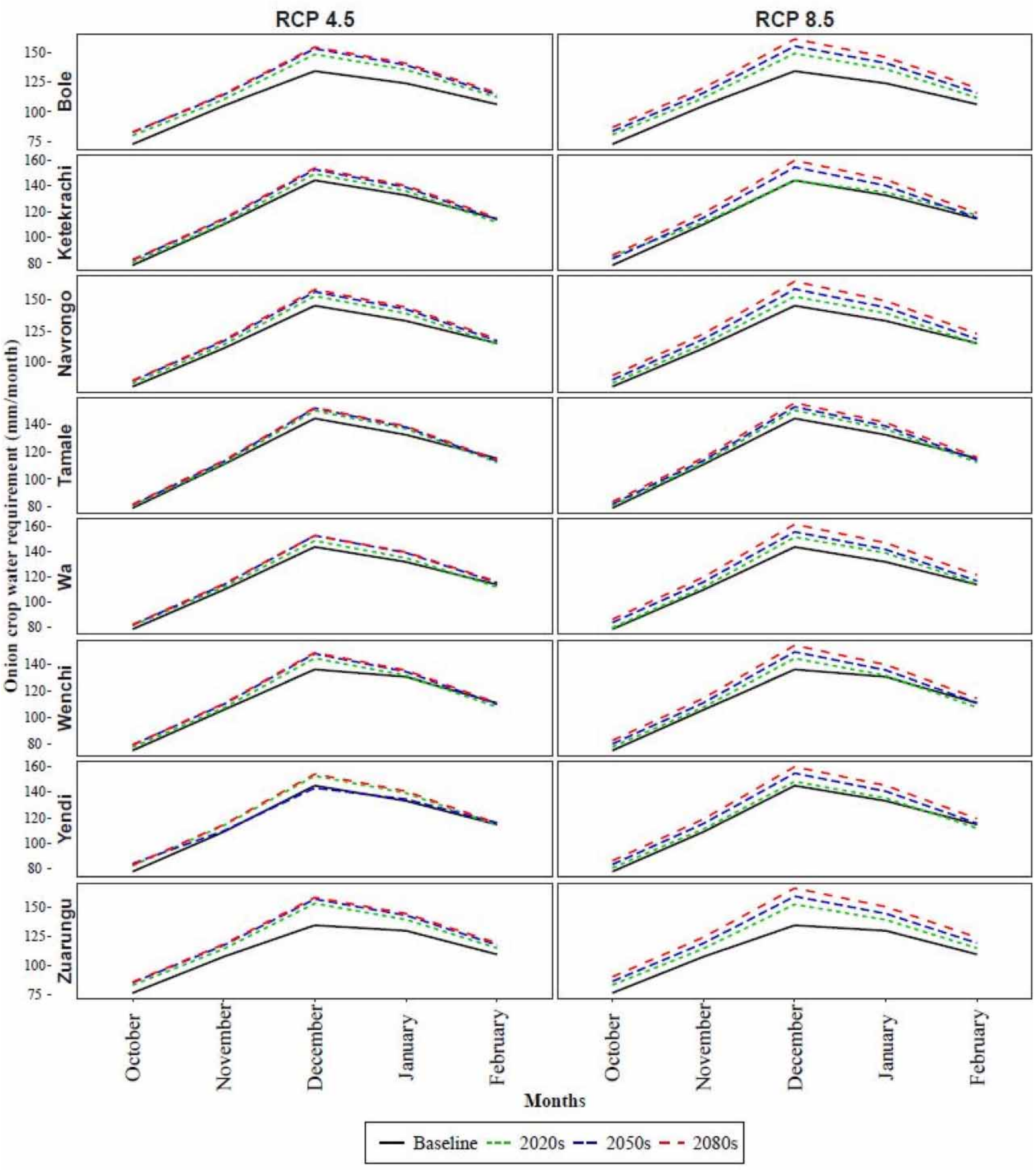


Figure 5 | Monthly crop water requirement for the baseline and future periods for onion.

respectively. At Yendi, a 4 and 1% increase was projected for the 2020s under RCP 4.5 and RCP 8.5, respectively; for the 2050s, the figures were 1 and 4% and finally 5 and 9% under RCP 4.5 and RCP 8.5, respectively.

Finally, at Zuarungu, an 8% increase was projected for the 2020s under both RCPs, 11 and 12% for the 2050s, and 12 and 17% for the 2080s under RCP 4.5 and RCP 8.5, respectively. The projected changes in the future periods for onions were almost the same as those for tomatoes; hence, they were not repeated.

The expected change in future CWR for both crops is less severe, moderately severe, and very severe in the 2020s, 2050s, and 2080s, respectively, under both scenarios (see Figure 7). This is expected to even intensify under the RCP 8.5 scenario. Wenchi, Tamale, and Kete-Krachi are expected to record less than a 2% change in CWR for both crops in the 2020s under RCPs 4.5 and 8.5 (Figure 7). However, Bole and Zuarungu are expected to record the highest change in CWR (for crops) of more than 15% in the 2080s, especially under RCP 8.5 (Figure 7).

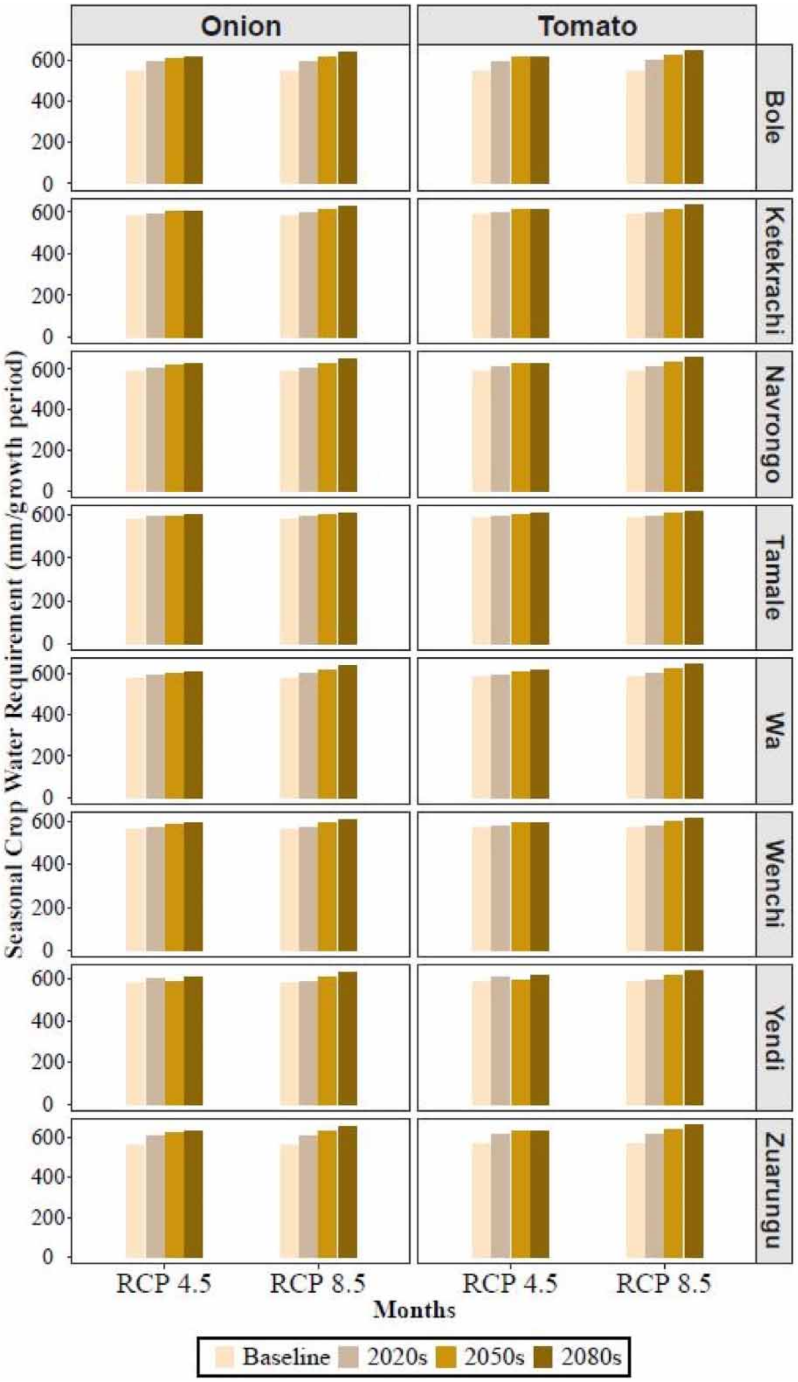


Figure 6 | Total estimated water requirement for the growing season for both tomato and onion per climate station.

3.4. Monthly CIR

The details of the monthly CIR for each station for tomato and onion are presented in Figures 8 and 9. Just like the CWR, irrigation requirements varied among stations and crops. The CIR was assumed to be zero for months that had precipitation amounts exceeding the CWR (Jahani *et al.* 2016).

For tomatoes, the least irrigation water requirement was recorded for October and then increased steadily through November and December reaching a peak in January, after which a decline was observed in February (see Figure 8). Reasonably, this is

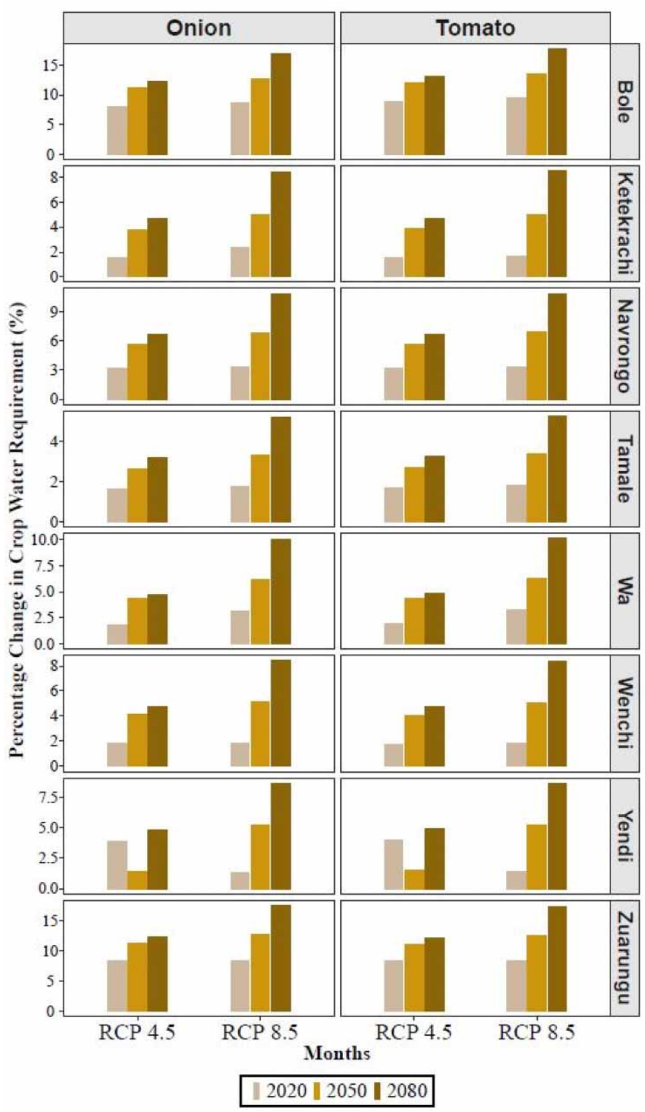


Figure 7 | Change in seasonal CWR for the baseline and future periods for onion per climate station.

because the soil moisture content is usually high at this time. This is mainly because it is just about the time that the rainy season ends, it is either the crops are still receiving some amount of rain or soil moisture content is high enough to meet crop water demands. Therefore, crops in this period require little or no external water supply to meet their water needs. Again, because crops are just at their initial growth stage at this time, they do not require high amounts of water for their metabolic activities; therefore, the amount of soil moisture is just sufficient for their needs (Sam-Amoah *et al.* 2013; Kariyama 2014).

For most of the stations, the baseline irrigation requirement was observed to be the least amount recorded and increased in the 2020s and 2050s, then declined in the 2080s. However, for stations like Bole, Kete-Krachi, and Zuarungu, the effective precipitation exceeded the CWR in the baseline period for October, indicating that there was enough moisture in the soil and therefore no need for irrigation; the irrigation requirement was observed to be zero (see Figure 8). Again, at Wenchi, irrigation requirements for October for the baseline period and all three future periods were also observed to be zero (see Figure 8). This observation is likely because this station is located within the humid zone, close to the humid region which receives rainfall till late November, and therefore at such times, there will be enough moisture in the soil to meet the evapotranspiration needs of the crops at that time.

Irrigation requirement for onions also showed the least records in October and then increased in November, peaked in December, and then gradually declined from January to February for almost all stations (Figure 9). Similar to the observation

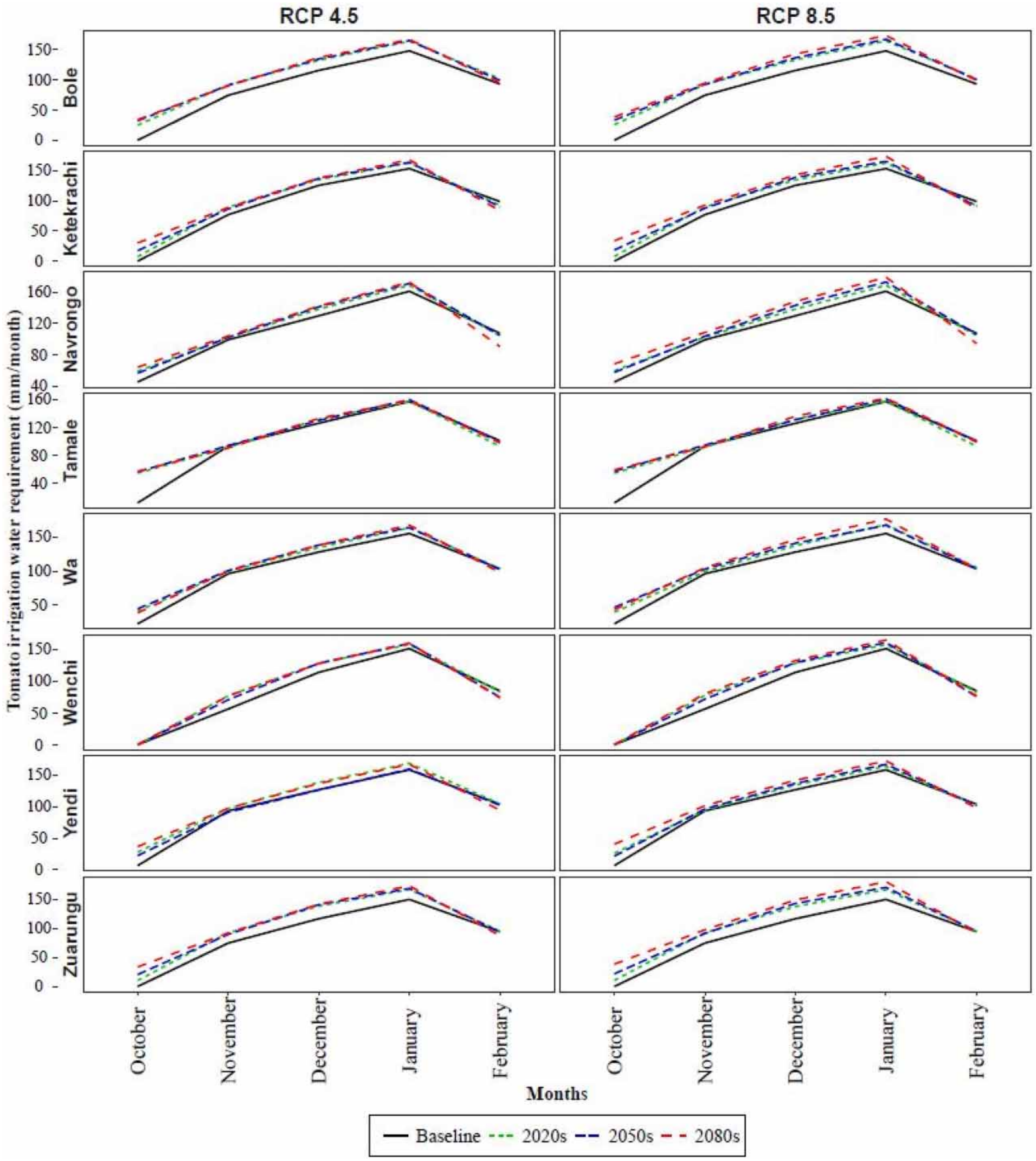


Figure 8 | Monthly CIR for the baseline and future periods for tomato.

made for tomatoes, the least irrigation requirement was recorded in the baseline period, and then the amounts were observed to increase in the future periods. Again, stations like Bole, Kete-Krachi, Yendi, and Zuarungu recorded zero irrigation requirements for October in the baseline period and Wenchi for the baseline and all future periods (see Figure 9).

The challenge with the observed peak in irrigation requirement occurring in either December or January for both crops is that most of the small (shallow) irrigation facilities such as wells and dug-outs start drying up or are entirely used up by this period of the dry season and therefore it becomes increasingly difficult for some farmers to obtain water for irrigation.

3.5. Seasonal CIR

The seasonal irrigation requirement (SIR) was generally the lowest for the baseline period for both crops. However, the projections reveal an increase in SIR in the future periods for almost all stations under RCPs 4.5 and 8.5 (Figure 10). Notably, for

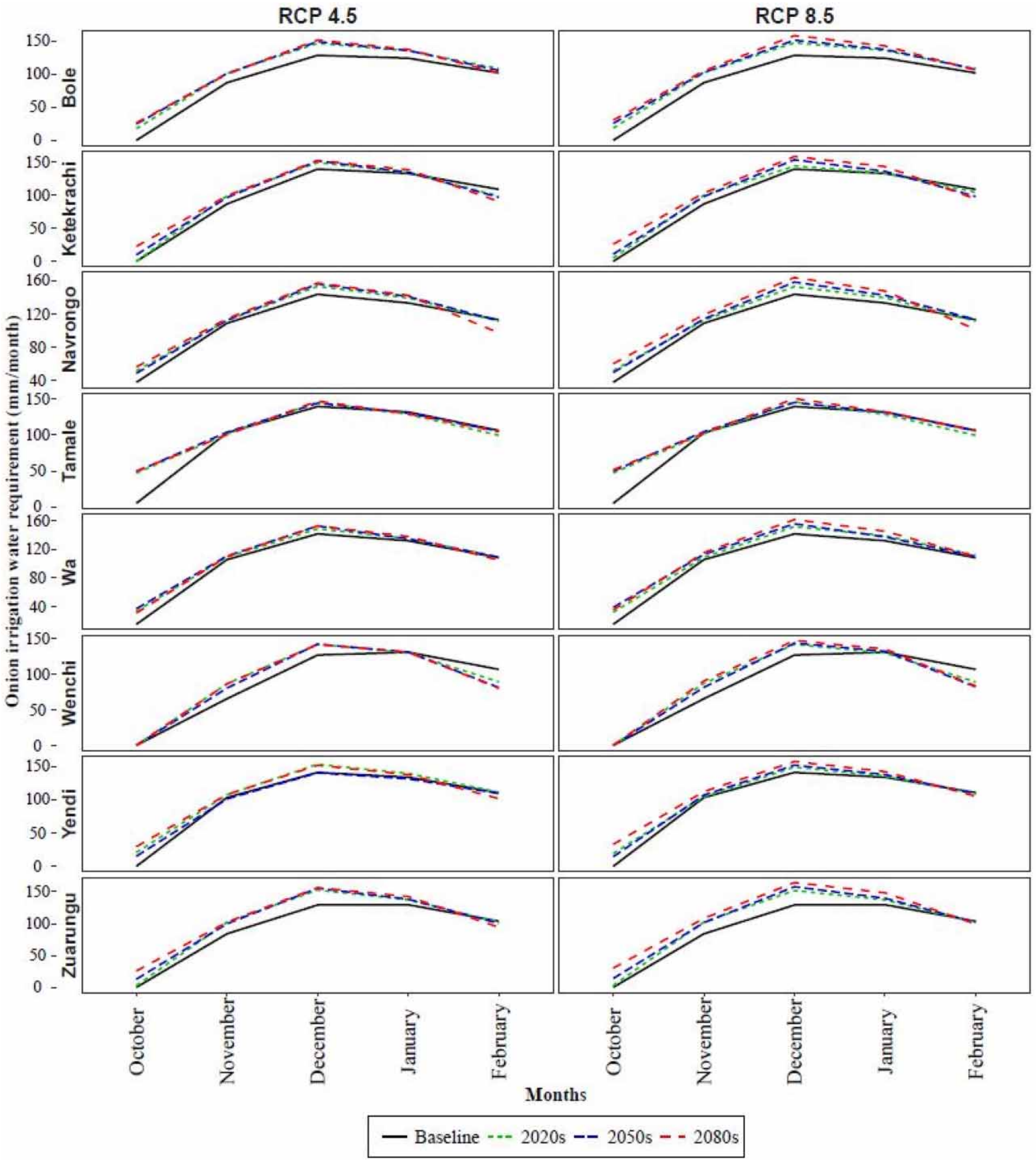


Figure 9 | Monthly CIR for the baseline and future periods for onion.

Wenchi and Yendi under RCP 4.5 for both tomato and onions, the 2020s recorded the highest increase, then a slight decline in the 2050s which then increased again in the 2080s. Under RCP 8.5, however, the highest increase was in the 2080s for both crops, although the decline in the 2050s was still present.

The highest irrigation requirement for both the baseline (500 mm/growth period) and future periods was recorded at Navrongo, whereas the least requirement of about 400 mm/growth period was recorded at Wenchi for both the baseline and future periods. This may be attributed to the locations of the stations. Navrongo is known to be a semi-arid location, while Wenchi is classified as humid. Accordingly, atmospheric water demand will be high, while precipitation will be expected to be low. As a result, the CWR and subsequent IWR will be higher as compared to Wenchi where there will be relatively higher rainfall amounts and low evapotranspiration rates due to its location in the humid climate.

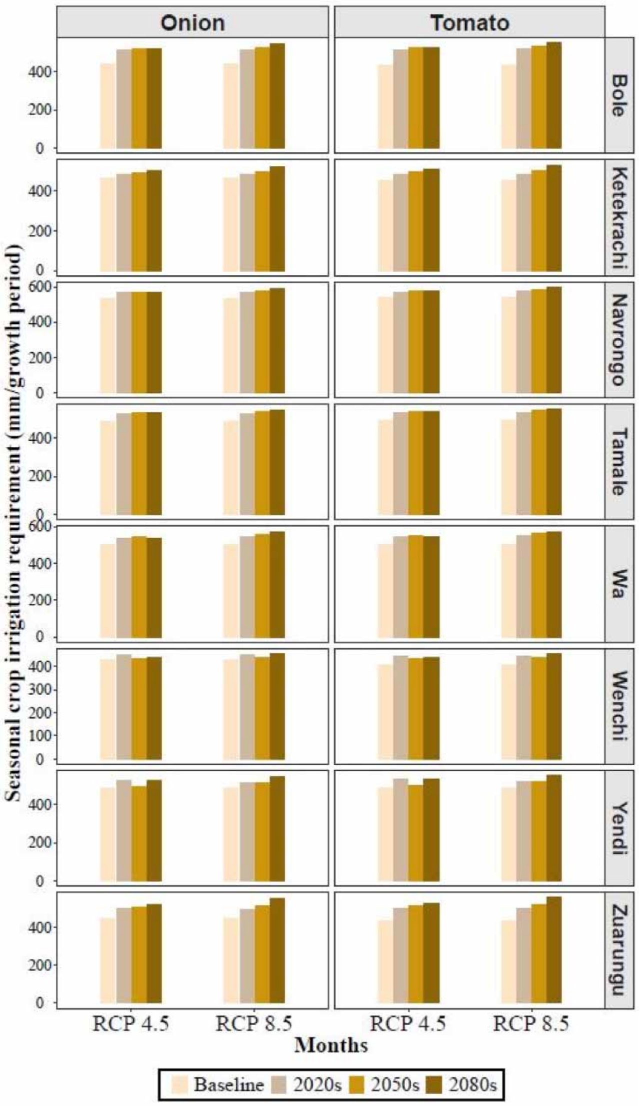


Figure 10 | Total estimated irrigation requirement for the growing season for both tomato and onion.

3.6. Change in seasonal CIR

The most notable changes in irrigation water requirements were recorded at Bole and Zuarungu, which have been classified as semi-arid and dry sub-humid, respectively (Figure 11).

At Bole, the change in irrigation requirement for tomatoes for the 2020s was 20% under both RCPs. Also, 21 and 22% were recorded in the 2050s, whereas 21 and 27% were recorded in the 2080s under RC4.5 and RCP 8.5, respectively. For onions, the change was relatively lower compared to that of tomatoes. For the 2020s, the projected changes were 15 and 16%, respectively, under RC4.5 and RCP 8.5, 17 and 19% for the 2050s, and then 17 and 23% for the 2080s.

For most of the other locations, the projected changes were relatively higher for tomatoes than for onions. However, for stations such as Navrongo, Tamale, and Wa, these changes were almost the same although those for tomatoes continued to be slightly higher. For others like Kete-Krachi and Wenchi, the projected changes for tomatoes were much higher than those of onions. As such, it will be a good idea that the cultivation of onions is encouraged at these locations. A similar rise in CIRs was recorded for the future periods at Navrongo by Asante (2009), who noted that the observed changes hinged on changing climatic conditions like increased temperature and distorted rainfall patterns.

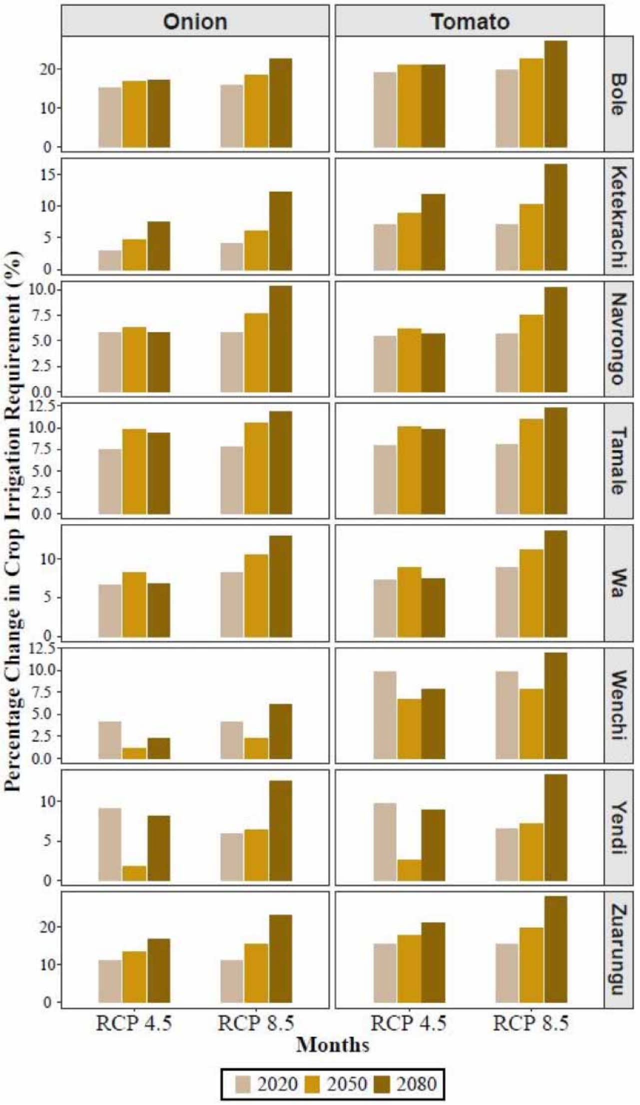


Figure 11 | Change in irrigation requirement for the growing season for tomato and onion for baseline and future periods.

4. DISCUSSION

4.1. Crop water requirement (ET_C)

The highest CWRs were observed to occur during the peak of the dry season (December–January). This is understandably the case because the crops are at the apex of their growth curve at this time, thus requiring more water for optimal growth. Again, because the crops are at their peak, parts like the leaves have fully developed their largest surface area, hence exposing a more substantial area for evapotranspiration, resulting in more water uptake by the plant (Allen *et al.* 1998). Metabolic activities are also at their highest and therefore require the relatively higher amounts of water (Irigoyen *et al.* 1992).

However, this period coincides with the peak of the dry season when there is no or very little rainfall occurring, and thus available soil moisture might not be enough to meet this requirement naturally. There are usually high evapotranspiration rates during this period, resulting in high water losses by plants. As a result, most farmers rely on water from wells, dug-outs, and dams for irrigation.

Considering the limited water resources and the increasing CWR, it would be good to plan the growing season, so it does not coincide with the peak of the dry season. Unfortunately, due to the short rainfall season in the SADA zone, the rains ceased in early October. Farmers often try to make the best of the dry season by planting their crops in early October, so they can harvest before the dry season gets most intense. However, as was observed from the results, the growth period of the chosen crops often lasts till the peak of the dry season. Therefore, for the sustainable farming of these crops, there will be the need to intensify the efforts at providing dams and reservoirs as well as other methods of capturing and storing runoff water during the rainy season, so that it can be used during the dry season (Ghansah *et al.* 2021; Akpoti *et al.* 2022).

Water requirements were observed to vary among these stations. This may be due to variations in climatic conditions such as solar radiation, temperature, and a range of others (Agodzo *et al.* 2003; Sam-Amoah *et al.* 2013). The locations in the southern part of the study area (Wenchi and Kete-Krachi) had relatively lower CWRs as compared to the location in the upper part of the study are closer to the Sahel. The stations in the lower part of the study are closer to the humid regions of the country and tend to be influenced by the humid climate, thus resulting in the relatively lower CWRs.

4.2. Change in CWR

Water requirement was found to increase from the baseline period to the future periods at almost all locations, an indication that the crops would require more water for their optimal growth under the future scenarios as compared to the baseline period. This is reasonably so since temperatures are projected to increase from the baseline periods through the future periods. This will consequently impact evapotranspiration rates and subsequently the water requirements in like manner.

The increasing temperatures will lead to high evaporation and transpiration rates from the soil and crops, respectively. Thus, the crops will require to take up more water from the soil to sustain their growth, while the soil moisture content might be so reduced that it will not be able to this demand.

For the baseline period, effective precipitation was relatively high. Consequently, lower amounts of water were required for irrigation.

4.3. Crop irrigation requirement

CIR was found to be directly proportional to CWR. Consequently, the lowest irrigation requirements were recorded in the baseline period and then the amounts increased in the future periods for the majority of the climate stations that were studied. This general increase in CIRs at all locations is in response to changing climate (O'Neill & Dobrowolski 2011; Fitzhorn 2012). As rainfall amounts are expected to decrease, and temperatures increase, soil moisture will be reduced, and the CWR will increase, hence leading to a high requirement for irrigation.

However, the Savannah is known to be plagued with perennial water scarcity, which poses a threat to dry season farming (Kasei 1988; Kasei *et al.* 2014; Issahaku *et al.* 2016). Hence, with the projected increases in temperature and subsequently in water requirements coupled with reduced rainfall amounts, this phenomenon is only expected to worsen.

To sustain agricultural activities during the dry season, farmers tend to rely on ponds, dams, and reservoirs for irrigation. Nevertheless, these water sources are also threatened by the projected future climate and the increasing demand for water by the crops.

4.4. Change in seasonal crop irrigation requirement

The projected changes in SIRs as presented in this study are an indication of the threat that faces agriculture under climate change. On the one hand, crops are expected to be requiring more water for optimal growth due to increased temperatures that result in higher evapotranspiration rates, while on the other hand, water systems have been projected to be drying up as a result of reduced rainfall amounts and higher evaporation rates. The effect of this is a possible collapse of agricultural activities, especially during the dry season, leading to famine as well as loss of jobs and livelihoods.

Several strategies have been proposed for sustainable agriculture in the semi-arid locations in the face of climate change and chief among them is the changing growing times of most crops to coincide with the growing period. However, Chowdhury *et al.* (2016) found that changing growing seasons does not resolve the challenge since CWRs may instead be compounded. Again, if agricultural activities cease during the dry season which lasts for about 9 months in the year, food security, as well as livelihoods, may be threatened due to the lack of jobs and productivity.

Also, looking at the projected increase in water requirements and the challenge of climate change, it sounds reasonable to suggest that these crops should instead be cultivated in the rainy season when there would be enough water to support their growth. However, onions and tomatoes are known to grow better under irrigated conditions where the amount of water they receive is appropriately monitored, and thus the dry season provides a better opportunity to do this since it is usually little or no rainfall (Yaji *et al.* 2012).

In planning for sustainable agriculture and effective water management, considerations need to be given to the types of crops that are cultivated and their water requirements in the face of climate change. Looking at the projected climate scenarios and subsequent water demand, there is a need to find sustainable ways of storing water, so that it will last long enough for the growing period of crops.

5. CONCLUSION

Crop failure resulting from changes in weather patterns and climate has been and remains a major challenge in the Savannah regions of Ghana. Although this situation is expected to worsen, the challenge has been in the ability to quantify the changes that are projected to happen. This study has shown that the amount of water required for optimum growth by crops varies with the location as well as with crops. The exact changes per location have been estimated. Most of the stations showed rises in water requirements for future periods. This observation implies that there is a need to find the ways of supporting dry season farming. These measures need to be resilient against climate change and may include rain-harvesting technologies that can capture runoff water in systems where there is little or no evapotranspiration and improved farming practices that optimize the sustainable use of water resources. There should also be advances in the provision of more drought-resistant and early maturing crop varieties that do require a relatively little amount of water for optimum growth. As per the findings of this study, interventions may need to be location-specific to meet the peculiar needs of the particular site. Otherwise, the 'one-size-fits-all' projects that we have been used to may not successfully address the problems they were intended to fix.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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