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Simulation of Grape Crop Future Water Requirement Using CROPWAT Model in Semi- Arid Region

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Abstract

Changes in the climate parameters are likely to influence crop water requirement due to evapotranspiration and precipitation variations. To understand this, we investigated the impact of climate change on crop water requirement of grapecrop in Ranga Reddy district, Telangana, India, a semi-arid climate region using CROPWAT model in conjunction with the climate scenarios derived from CimGen model.Baseline climate data for 31years (1980-2010) of the study area were used to generate the future climate data for the years 2020 and 2050.Based on ClimGen model generated future climate data for the study area it is observed that maximum temperature may increase by 1.04°C and 1.72 °C for the years 2020 and 2050 respectively compared to baseline data of 1980-2010. The projected average monthly minimum temperature may decrease by 1.92 °C and 3.62 °C for the years 2020 and 2050 respectively. It also s observed that the average annual rainfall is to be increased by 2% and 5% for the years 2020 and 2050. Irrigation and Crop Water Requirements (CWR) was simulated using CROPWAT model for the present and the future. The results show an increase in grape crop water requirements of 3.5%and7% and irrigation water requirements of 4% and 12% for the years 2020 and 2050 respectively.

Key words: Crop water requirement, Climate change, CROPWAT model, Grape, ClimGen model

1. Introduction

Horticulture is a potential agricultural enterprise in accelerating the growth of economy. It plays a significant role in the country's nutritional security, poverty alleviation and employment generation programs,and provides a wide range of options to the farmers for crop diversification. At presentin India, horticulture is contributing 24.5% of GDP from 8% land area(1). On account of significant production increase in horticultural crops across the country, a golden revolution is in the offing. Nevertheless, horticulture is practiced in very vast region of the country due to itsadaptability to wide range of agro-climatic conditions.Thus, one of the horticulture crops (grape), which is widely practiced in India, was identified for the present study. To increase the production of grape fruit crop to meet the demands of growing population adequate irrigation is one of the requirements. The grape crop requires supplemental irrigation to ensure maximum yield (2). But, the likely changes in the climate will impact on agriculture andwater resources. A changing climate could lead to frequent drought and alter the grape crop water requirement. The changein temperature and rainfalldistribution patterns increases the vulnerability of fruit production. However, it can be minimized by irrigation management practices such as maintaining adequate water supplies to avoid water deficits (3). Several studies have reported the effects of climate change on irrigation. For example,(4)reported an annual increase of 3-5% of irrigation water requirement by the year 2020, and an overall increase of approximately five-fold by the year 2070. However, according to(5)theadverse impact of climate change could be substantially reduced by irrigation management and selection of appropriate planting dates.

In recent decades, numerous computerized simulation models ((6)**;** (7); (8)) have also been developed to estimate crop irrigation requirement using soil water balance approach. The water balance approach combines information on the crop, soil and weather to estimate a soil water deficit. Irrigation is scheduled according to an allowable deficit that may be varied from season to season. The potential drawback of this approach is the high computational requirement and is non-user friendly. It uses approximation in the potential evapotranspiration computation. These models also lack explanation on water supply planning and are based on single field irrigation.

However, with changing temperature and rainfall patterns, more precise irrigation management is needed, which is possible only by determining crop water requirements.Theaccurate planning and delivery of the requiredamount of water in time and space is important particularly in a semi-arid climate. The non-uniform distribution of rainfall, limited water holding capacity of soils, and extreme sensitivity of crops to water stress requirementlead to efficientscheduling ofirrigation (**7**).Therefore, in view of the presentstatus of water resources and increasing demand of water for meeting the requirements of rapidly growing population of thecountry as well as the problems that are likely to arise in future, a holistic, well planned long-term strategy is needed for sustainable water resources management for grape crop in India.

The present study was conducted with the objectives to analyze the effect of future climate scenarios on the grape crop water requirement, and how future climate scenarios will affect the irrigation needs for the years 2020and 2050.The CROPWAT model (9) was selected to be used in this study on the basis of previous tests and satisfactory performance across the world-wide locations under varying climate circumstances. It was used to analyse climate data and water requirement of grape fruit crop. For future climate data generation ClimGen weather generator was used. ClimGen weather generator is an effective tool for the parameterization of weather data and the generation of long-term weather data.It performs well in simulation of weather data series (10). Generally, the generated weather data is found very similar to the observed data i.e. monthly precipitation distribution, variances, monthly means and variance of minimum and maximum air temperatures (11).Therefore this study has relevance for agricultural modeling applications particularly where limited observed records are available.

2. Study Area

Semi-arid climate is considered suitable for the horticulture crop. Therefore, we have selected an area of grape fruit crop for the study (Ranga Reddy district, Telangana, India), which is located in semi-arid climate region (Fig. 1). Statistics shows that the state of Telangana is one of the top grape fruit crop producing states (12). Ranga Reddy district is located in the central part of the Deccan plateau and is extended between 16^{o} 30' and 18^{o}20’ North and 77^{o} 30' and 79^{o}30’ East.

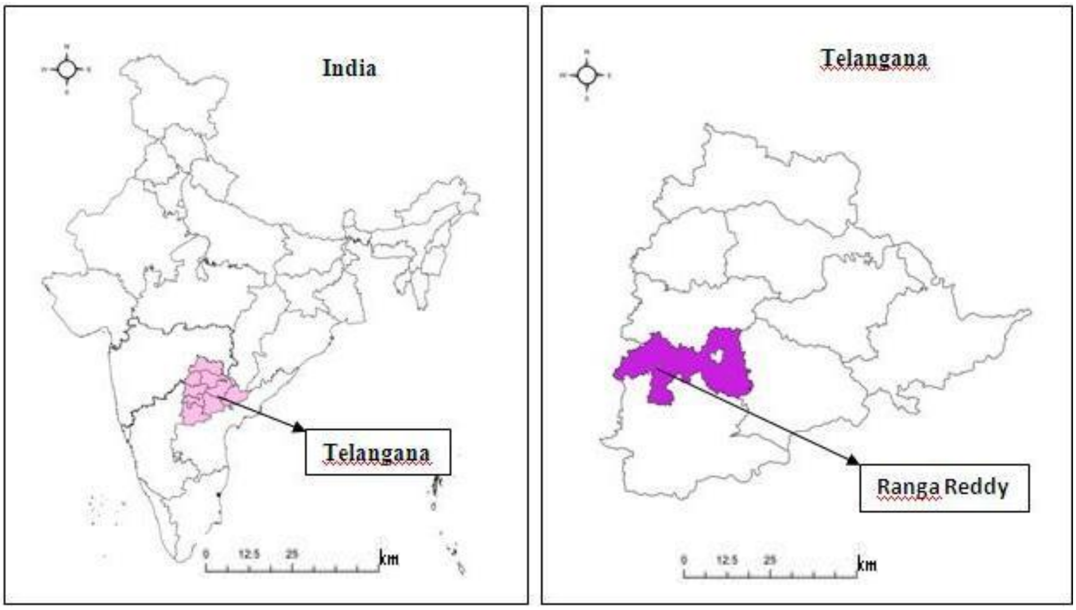

Fig. 1 - Study area: Semi-arid region; district Ranga Reddy, Telangana, India

3. Methods

The entire approach can be divided into 5 parts: 1. Data collection, 2. Trend analysis using baseline data, 3. Generation of future climate data using ClimGen model, 4. Calculation of Crop Water Requirement using CROPWAT model, and 5. Comparing the crop water requirement (computed with baseline and generated data).

3.1. Data Collection

Daily meteorological data (daily maximum temperature, minimum temperature, wind speed, sunshine hours, rainfall and radiation) for the study area were collected from Agricultural Research Institute (ARI), Rajendranagar, for the period 1980-2010. Crop data such as length of crop (development stages in days), and crop coefficient (Kc for grape crop for all seasons) were collected from Food and Agriculture Organization (13) and Horticulture department of Ranga Reddy district.

3.2. Trend Analysis Using The Baseline Data

CROPWAT-8.0model developed by the Land and Water Development Division of FAO for planning and management of irrigation is a computer program that uses the FAO, Penman-Monteith model to calculate referenceevapotranspiration (ET_o), crop water requirements (ET_C) and crop irrigation requirements (9). Datasets used as inputs in the CROPWATmodel are: climatic, crop, soil and irrigation. The climatic data includes daily maximum and minimum temperatures, mean daily relative humidity, daily sunshine, wind speed and rainfall. The crop parameters are: planting date, crop coefficient including K_C values, stage days, root depth, and depletion fraction. The soil data includes total available soil moisture, maximum infiltration rate, maximum rooting depth and initial soil moisture depletion (% of total available moisture).Soil moisture is a key variable in controlling the exchange of water and heat energy between the land surface and the atmosphere through evaporation and plant transpiration. Total available soil moisture content defined as the difference in soil moisture content between Field Capacity (FC) and wilting point. Infiltration is the process by which water on the ground surface enters the soil. Maximum rain infiltration is a function of rain intensity, soil type and slope class. Maximum rooting depth determined by genetic characteristics of the plant. Initial soil moisture depletion indicates the dryness of the soil at the start of irrigation. Day wise observations of the climatic data mentioned above were extracted from themeteorological data of the past 31 years (1980-2010). Year and month wise mean monthly maximum and minimum temperatures, humidity, wind speed and sunshine hours were worked out and trends of all input parameters of CROPWAT were analysed.

3.3. Future Climate Data Generation Using Climgen Model

ClimGen model is used to generate weather data on the principles similar to those in WGEN (14).ClimGen is a daily time step stochastic model that generates daily precipitation, minimum and maximum temperature, solar radiation, humidity and wind speed data. The model requires inputs of daily weather variables to calculate parameters for any length of period for a location of interest (15;16;17). In this study, the model was evaluated by using historical data of 1980-2010. The mean monthly observed rainfall data were compared with the generated data by simple regression analysis. The percent difference (E) between observed (Obs) and simulated (Gen) mean monthly rainfall data was calculated for 31 years by performing t-test and F-test using the following equation:

$$\%\text{ differeance} = \frac{\text{Gen}-\text{Obs}}{\text{Obs}} \times 100 \quad (1)$$

Daily maximum and minimum temperature for the years mentioned above were used for the purpose of comparing the observed and generated temperature data to evaluate the ClimGen modelfor climate change/variability analysis. Besides t-test and F-test, the model was validated by using the refined d_r-index of agreement (18) as given below:

$$d_r - \text{index} = 1 - \frac{\sum_{i=1}^{n} |P_i - O_i|}{2\sum_{i=1}^{n} |O_i - \overline{O}|} \quad (2)$$

P_i = model predicted value
O_i = observed value
$\overline{O}$ = observed mean monthly value

After evaluating the model, the daily rainfall, maximum and minimum temperature were simulated to generate a long term data (2011-2050) for trend analysis based on past observed data (1980-2010) using theClimGenmodel.

3.4. Calculation of Crop Water Requirement using CROPWAT model.

Crop Water Requirement (CWR) is defined as the depth of water needed to meet the water loss through evapotranspiration for a disease-free crop growing in a large field under non-restricting soil conditions including soil water and fertility, and achieving full production potential under given growing environment (19).Crop water requirement or crop evapotranspiration (ET_{CROP}) is determined by ET_0 and Crop Coefficient (K_C) in the following well-established equation (20):

$$ET_C = K_C' * ET_o \quad (3)$$

Where, ET_C = Crop evapotranspiration
ET_o= Reference evapotranspiration
K_C = Crop coefficient

Allen et al. (1998) recommended FAO, Penman-Monteithmethod - standard method to calculate the reference evapotranspiration (ET_0), using climatic data. Different grape crop growing stages and $K_C$values standardized by (20) were considered for simulation of grape crop water requirement. Grape crop total growing period, growth stages and K_C values were also collected from

Horticulture Department, Grape Research Institute, Hyderabad and compared with the K_C values standardized byFAO. Using ET_o(baseline data),crop,soil and K_C values of grape crop water requirement (CWR) for the study area were calculated using the above equation. ET_ocalculated for the study area was compared with ET_odata generated by using Evaporation pan inthe field.

Then, irrigation water requirement of grape crop was computed. The irrigation water requirement represents the difference between the crop water requirement and the effective precipitation (21). We used United States, Department of Agriculture (USDA) Soil Conservation Service method in CROPWAT model to calculate Effective precipitation. In USDA SCS method the following equation is used for calculating the effective rainfall:

PE = Ptot * 125-0.2 Pto for Ptot< 250 mm (4)

PE = 125 + 0.1*Ptot for Ptot> 250 mm
Where,
PE = effective rainfall, mm
Ptot = total rainfall, mm

3.5. Comparing The Water Requirement Computed With Baseline Data And Generated Future Data

By using input of ClimGen generated parameters (daily maximum temperature, minimum temperature,precipitation, and relative humidity) in CROPWAT model future water requirements for grape crop was calculated for the period 2020-2050. The trend analysis of baseline climate data was carried out to know the deviation in data. The computed water requirement from baseline data was compared with the computed water requirement generated by ClimGen model for future grape crop.

4. Results and Discussion

4.1. Reference Crop Evapotranspiration (ET_o)

The input parameters of CROPWAT were analyzed, year wise and month wise for the study area. The analysis shows increasing trend in the maximum temperature of 1^{o}C (2.35%) and decreasing trend in the minimum temperature of 2^{o}C (24.69%) for the period 1980-2010.Month wise mean minimum and maximum temperature for the period of 31 years for the study area is given in Table1. The lowest and highest mean temperature (20.7^{o}C and32.4^{o}C)is observed in the months of December and May respectively.

In the simulated values of crop evapotranspiration (ET_o) (Table2),the highest value 6.9 mm day^{-1} and lowest value 3.1 mm day^{-1}are observed in the month of May and December respectively. During the summer,increase in the $ET_o$is due to the increase in temperature.

The day wise pan evaporation (for the period 1980-2010) was recorded and the month wise mean values for the same period were computed. The values of ET_o

$_{(CROPWAT)}$ andET_o $_{(PAN)}$ were plotted to understand the relationship and apositive linear relationship (r^2 =0.973) was observed.$ET_{o(CROPWAT)}$ and $ET_{o(PAN)}$ (Fig. 3) indicated that CROPWAT model predicts the crop evapotranspiration (grape fruit crop) reasonably well and may thus be used for assessment of ET_o.

Table 1 - Mean Monthly Temperature (° C) (month wise average data for the period (1980-2010)

Parameter/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Min Temp ((^oC)	13.7	16.1	19.7	23.2	25.7	24.3	23.1	22.6	22.3	19.8	15.9	12.7	19.9
Max.Temp.((^oC)	29.2	32.3	35.7	38.1	39.2	34.5	31.1	29.9	30.7	30.8	29.4	28.5	32.5

Table 2 - Estimated ET_ousing CROWAT 8.0

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
ET_o (mm/day)	3.4	4.4	5.2	5.9	6.9	6.0	4.8	4.2	4.1	3.9	3.5	3.1	4.61

4.2 Evaluation Of Climgen Weather Generator For Future Projections

To evaluate the data generated by ClimGen model, statistical analyses and comparison with original data were carried out. The statistical test result showed that there is a good agreement between the observed and simulated data in terms of its monthly precipitation, distribution and variances, monthly means and variance of minimum and maximum air temperatures. Probability (p-value calculated by t-test and F-test) for monthly means and coefficient of variation, and percent difference (negative value shows model under estimation) are shown in Table 3. As the d_r- index values are within 0.5, the model predictions can be considered satisfactory and the same has also been confirmed by the t and F tests (Table 3).

Table 3: Comparison between the observed and generated monthly rainfall (mm) data

Months	Obs Mean	Gen Mean	Obs CV %	Gen CV%	% difference of mean	t value at 5% p	F value at 5% p	d_r - index
Jan	5.21	4.57	49.35	47.06	-0.12	0.47	0.8	0.37
Feb	5.63	4.85	38.34	44.93	-0.14	0.16	5.12	0.57
Mar	24.91	24.25	65.21	70.86	-0.03	0.34	1.33	0.29
Apr	24.28	24.07	109.83	123.28	-0.01	0.47	1.47	0.32
May	34.55	33.94	95.61	122.98	-0.02	0.22	1.13	0.26
Jun	105.06	96.46	199.2	194.49	-0.08	0.27	1.08	0.48
Jul	159.11	159.89	177.37	200.30	0.00	0.32	0.97	0.24
Aug	172.56	166.06	177.48	245.40	-0.04	0.15	2.20	0.47
Sep	138.69	137.65	168.85	237.38	-0.01	0.46	1.73	0.31
Oct	95.08	98.62	120.49	144.03	0.04	0.23	1.10	0.30
Nov	27.75	23.75	50.84	71.00	-0.14	0.34	3.49	0.48
Dec	4.10	5.54	46.49	40.49	0.35	0.12	0.25	0.10

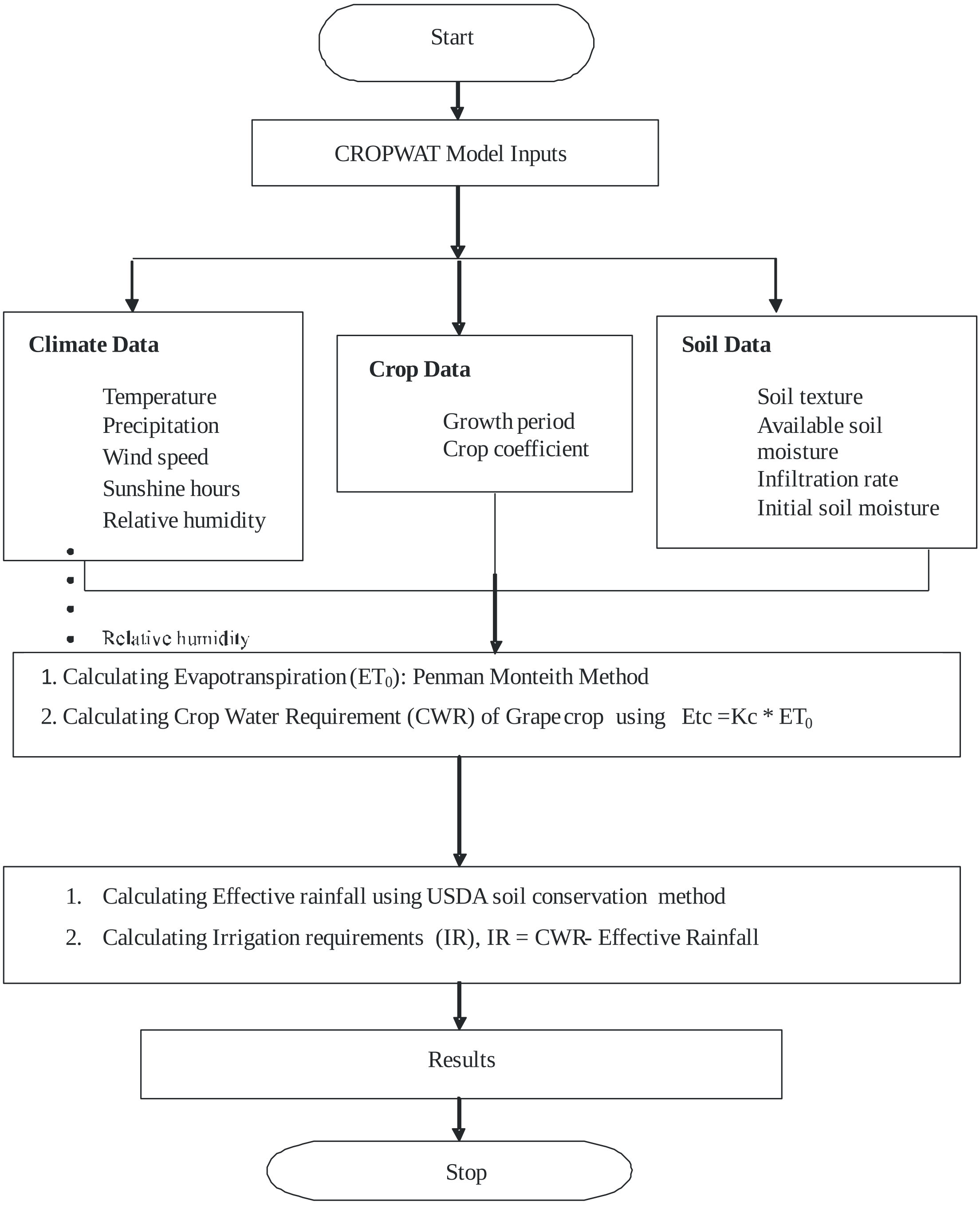

Fig. 2 - Flow chart for calculation of crop water requirement using CROPWAT model

The long term data generated by ClimGen model are close to the observed rainfall, maximum temperature and minimum temperature data (Fig.4a-c). Generated annual and seasonal rainfall data showed a very little variation in the trend. It is observed that there will be an increase of 5% annual rainfall in the study area by 2050. For climate change/variability study, daily maximum and minimum temperatures data were selected from observed data of 1980-2010 to generate data for the period of 2011-2050. From the trend line analysis, it is estimated that there will be an increase in maximum temperature of 1.04°C and 1.72°C by the years 2020 and 2050 respectively and there will drop in the minimum temperature of 1.92 °C and 3.62 °C by the years 2020 and 2050 respectively is observed.

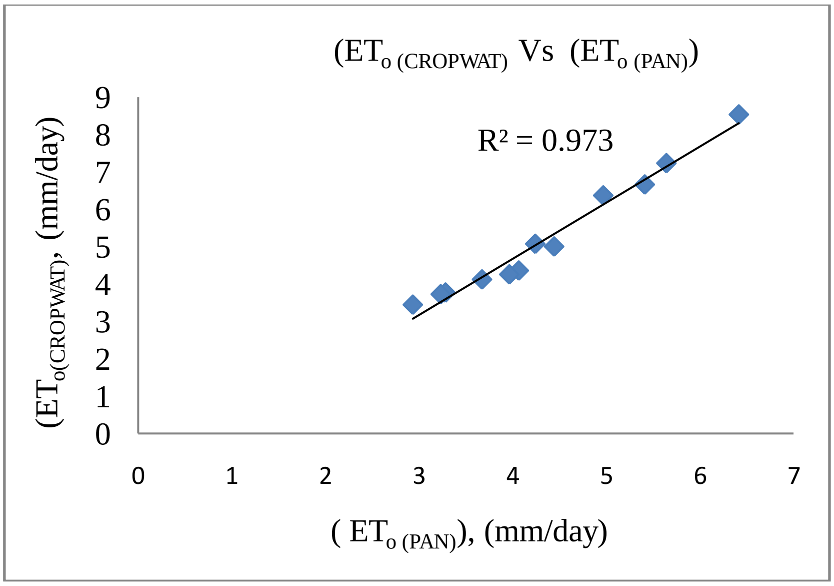

Fig.3–ET$_{o(CROPWAT)}$ Vs ET$_{o(PAN)}$for the study area

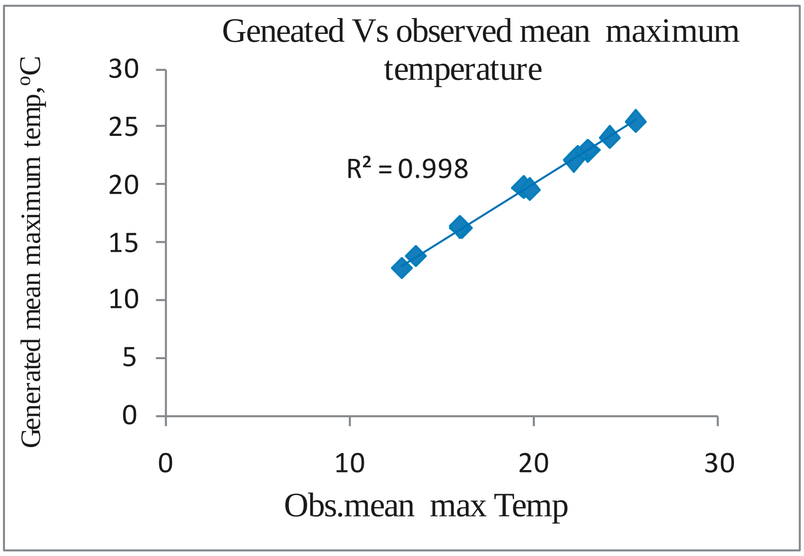

Fig.4a - ClimGen generated maximum temperature compared with observed data

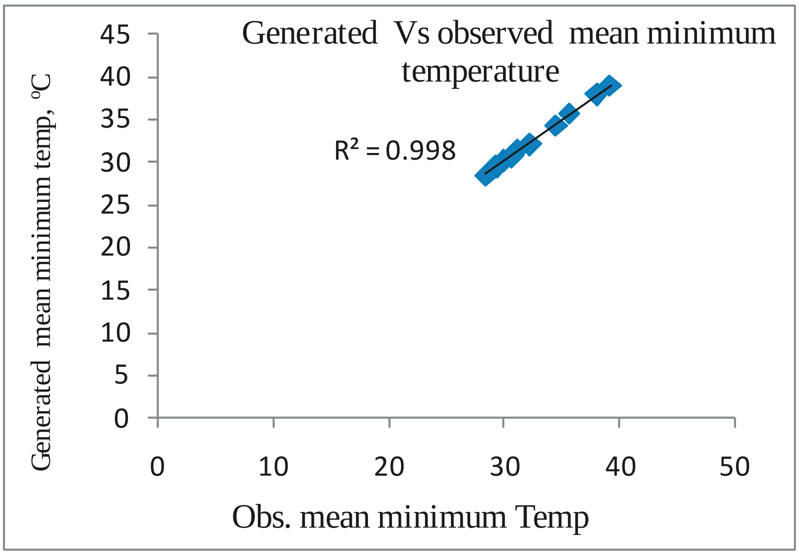

Fig.4b - ClimGen generated minimum temperature compared with observed data

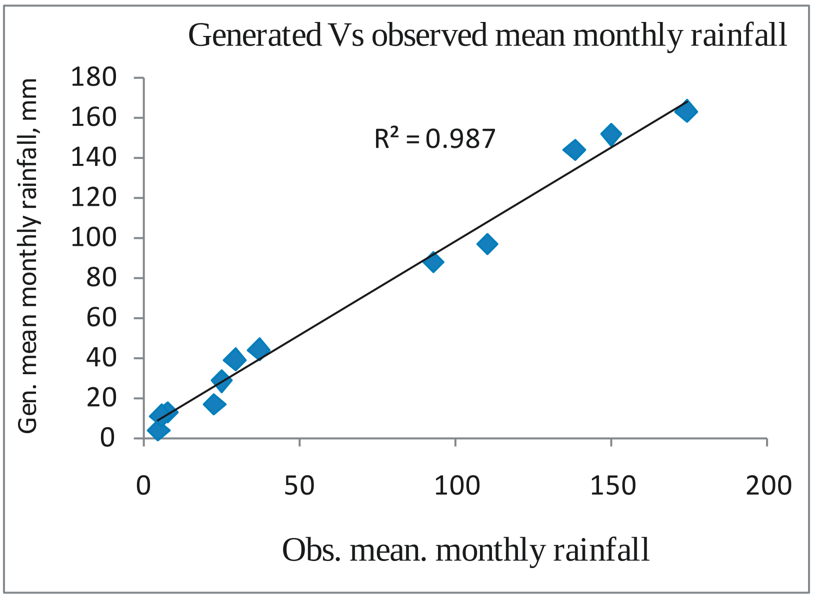

Fig.4c - ClimGen generated rainfall compared with observed data

4.3. Simulation of Crop Water Requirement (CWR) of grape fruit crop using baseline data

CWR was determined from ET_o and crop coefficients (K_C), based on well-established procedure (**FAO, 1977**), using the following equation:

$ET_C = K_C' * ET_o$ (5)

Where, ET_C = Crop evapotranspiration
ET_o= Reference evapotranspiration
K_C= Crop coefficient.

First, the potential ET_o was estimated, using the Penman-Montieth equation (9) given in the CROPWAT model using the baseline climate data (daily data of: maximum and minimum temperature; wind speed; sunshine hours; relative humidity; and rainfall) for the period 1980-2010. The crop coefficient (K_C) values provided by (9) were used for the simulation (CROPWAT model). The values of 0.30, 0.85 and0.45 were used for K_C initial, K_C mid and K_C finalrespectively for grape crop. The crop development stages values of 150, 50, 125, and 40 days of 365 days for the wholegrowing season were used in the simulation.

The soil type at selected location was red sandy loam. Total available soil moisture (FC - WP) for this type of soil was equal to 100 mm/meter and maximum rain infiltration rate was equal to 30 mm/day.The dates of sowing and harvesting of grape are taken from (21**).**These dates are compared with field experiments in the selected districts. The planting date of grape crop is taken as April. The same dates are used in simulation of water requirement using baseline data and using future climate data.

The grape crop initial stage is between April to August, development stage is between September and middle of October. The grape crop middle stage is between end of October and middle of February. The lateral stage of grape crop is between end of February to April first week

Then, the grape crop water requirement was simulated usingET_o(baseline data),crop,soil data, and K_C values of grape ($ET_C = K_C' * ET_o$) in CROPWAT model. After calculation of CWR, grape crop irrigation requirement was computed (Table 4). The irrigation waterrequirement indicates the difference between the cropwater requirement and the effective precipitation (21).

Table 4 - CROPWAT simulated CWR and Irrigation requirement for grape crop using ClimGen model

Climate change scenario	ET_o (mm/season)	CWR (mm/season)	Effective precipitation (mm/season)	Net irrigation requirement (mm/season)
Baseline climate data	4.61	865.80	640.50	469.00
ClimGen-2020	4.66	892.90	665.90	485.00
ClimGen-2050	4.90	911.90	674.5	525.90

Results indicate that CWR of grape crop may be the highest during January to March during late stage and lowest during June to August during initial stage. Results indicate that irrigation requirement may be the highest during January to

March during late stage of grape. The irrigation requirement may be zero during July to September because intensity of rainfall is high during July to September.

4.4. Simulation Of Future Water Requirement Of Grape Fruit Crop

The generated climatic parameters such as maximum and minimum temperature and precipitation using ClimGen model arein good agreement with the observed data as shown in Fig.4a-c. Thus, data generatedfor future climate were used as input to CROPWAT model and simulated future crop water requirements and irrigation requirements of grape fruit crop (Table 4).

Based on ClimGen model the maximum temperature in the study area showed the maximum increase of 1.04^{o} C and 1.72^{o} C for the years 2020, 2050 respectively compared to baseline data of 1980-2010.The projected average monthly minimum temperature may decrease by 1.92^{o} C and 3.62^{o} C for the years 2020 and 2050 respectively. The increase in maximum temperature resulted increase in ET_o as estimated by Penman-Montieth equation.

For grape crop growing season,CWR for the years 2020 and 2050 is predicted to be increased of 3.5% and 7%respectively using the future climate datarelative to the baseline data of 1980-2010 and irrigation water requirements for the years 2020 and 2050 is predicted to be increased of 4% and 12%respectively (Table 4). Results indicate that CWR of grape crop for 2020 and 2050 may be the highest during January to March during late stage, and the lowest during June to August in initial stage of grape crop. Results also indicate that irrigation requirement may be the highest during January to March in the late stage of grape crop

5. Conclusions

The climatic parameters such as maximum and minimum temperature and precipitation using ClimGen model were generated and were found in good agreement with the observed data.Overall, the model predictions were rated very high to be used for climate change assessment in semi-arid region. Analysis indicated increasing and decreasing trend in the maximum and minimum temperature respectivelyfor the period 1980-2010. The increase in maximum temperature resulted to the increase in ET_ovalues.It is estimatedthat there will be an increase in maximum temperature of 1.04^{o}C and 1.72 ^{o}C by the years 2020 and 2050 respectively. Whereas, drop in the minimum temperature of 1.92^{o} C and 3.62 ^{o} Cby the years 2020 and 2050.

The results also indicated that by the years 2020 and 2050, the grape crop water requirement will increase of 3.5%and7%and irrigation water requirements of 4% and 12%respectively. Thus, it is recommended to include analysis on extreme events of both precipitation and temperature during the growing seasons in the future studies. Adaptation measures, such as efficient irrigation scheduling for crop producers can bedeveloped for sustainable production under various climate change scenarios. Ingeneral, it is concluded that the climate change is very likely to affect theoverall waterresources in the region. Furthermore, extreme variation in precipitation will necessitate precise control of timing and volume of irrigation applications.

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