Pak. J. Agri. Sci., Vol. 56(2), 443-450; 2019
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/19.7194
http://www.pakjas.com.pk

IMPACT OF CLIMATE CHANGE ON GROUNDWATER FLUCTUATION, ROOT ZONE SALINITY AND WATER PRODUCTIVITY OF SUGARCANE: A CASE STUDY IN LOWER CHENAB CANAL SYSTEM OF PAKISTAN

Muhammad Mohsin Waqas[1], Syed Hamid Hussain Shah[1], Usman Khalid Awan[2], Muhammad Arshad[1] and Riaz Ahmad[3]

[1]Department of Irrigation and Drainage, University of Agriculture, Faisalabad, Pakistan; [2]International Center for Agricultural Research in Dry Areas, Cairo, Egypt; [3]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan.
***Corresponding author's e-mail: mohsinwaqas333@gmail.com**

Impact of climate in Pakistan is certain and its impact assessment is essential for the evaluation of irrigation system. In this study, impact of climate change on groundwater, root zone salinity and eventually on water productivity was assessed. Climate change data were assessed using the Hadley Climate model version 3 (HadCM3) and statistical downscaling was performed using statistical downscaling (SDSM) model. Further, bias correction was applied for the enhancement of SDSM results. Soil Water Atmosphere Plant (SWAP) model was used for the analysis of groundwater recharge, root zone salinity and water productivity under changing climate. Soil moisture and root zone salinity data were collected from the field for the performance of the calibration and validation. Automatic calibration was performed by integrating the SWAP with PEST. Water productivity analysis was performed for base period (1980-2010) and midcentury (2040-2069) under A2 and B2 climate change scenarios. Results shows that the groundwater depletion was less under the A2 and B2 scenario during the midcentury as compared to base period. Average annual groundwater depletion variation reveals 142 mm to 143 mm during base period and 121 mm to 124 mm under A2 and 117 mm to 120 mm under B2 scenario, respectively. While, average annual root zone salt accumulation was found 28 mgcm^{-3} to 21 mgcm^{-3} during base period and 26 mgcm^{-3} to 19 mgcm^{-3} under A2 and 27 mgcm^{-3} to 21 mgcm^{-3} under B2 scenario. Similarly, average annual water productivity was found 3.9 kgm^{-3} to 4 kgm^{-3} during base period, 3.4 kgm^{-3} to 3.6 kgm^{-3} under A2 and 3.2 kgm^{-3} to 3.4 kgm^{-3} under B2 scenario. Study reveals that the climate change has positive impact on the groundwater recharge and root zone salt accumulation. The results related with water productivity, salt mass accumulation and groundwater variations under changing climate suggest that sugarcane will be profitable business in future and environment will be sustainable.

Keywords: Climate change, anthropogenic factors, water productivity, irrigation water, SWAP, SDSM, IBIS

Abbreviations: IBIS (Indus Basin Irrigation System), SWAP (Soil Water Atmosphere Plant), GCM (General Circulation Model), SDSM (Statistical Downscaling Model), HadCM3 (Hadley Centre Coupled Model version 3), SD (Statistically Downscaling), LCC (Lower Chenab Canal), Bias Correction (BC), Partial Correlation (P.r), ETp (Potential Evapotranspiration), PEST (Parameter Estimation Technique), A2 and B2 (Climate Change Future Scenarios), Representative Concentration Pathways (RCP), SC1 (Sugarcane Field 1) and SC2 (Sugarcane Field 2)

INTRODUCTION

Climate change and variability due to the anthropogenic factors and natural process may results the serious environmental issues during the 21st century. Recently, increases in temperature of 1.8-4°C in 2090-2099 relative to 1980-1999 was estimated by the IPCC Fourth Assessment Report (AR4), and climate variability and change are projected to result in the increases of the extreme events of drought, floods, temperature (Trenberth *et al.*, 2007; Shakoor *et al*., 2018). Climate change made the big challenge to ensure the food security under the swift increasing population, while preserving the sustainability of the resources (Rosenzweig *et al.*, 2013).

Assurance of food security and the country GDP requires the farming under the adoption of the climate change in Pakistan. Agriculture sector is the biggest sector in Pakistan and plays a significant role in country economy. Agriculture share in the GDP is 19.8 percent and providing the income to the 42.3% of the country labour (GOP, 2016). Irrigated agriculture in the Pakistan is dependent on the surface water available in the system along with supplemental irrigation from the groundwater. In irrigated agriculture based on the water availability, more crop per drop is the big challenge (Khan *et al.*, 2006). This directed to evaluate the water productivity especially under the climate change.

Sugarcane is the biggest food contributor crop, 75% of the human consumed worldwide sugar is produced from the sugarcane (De Souza *et al.*, 2008). Due to the revolution in the industrial sector, sugarcane is not just bounded for the production of sugar, it is also providing the chipboard, alcohol, paper and many more products during the parallel process of sugar formation. In Pakistan, sugarcane cultivation covers 5% of the total cropped area and put Pakistan at 5th position based on sugarcane production, 7th based on sugar production and 8th based on sugar consumption in the world (Nazir *et al.*, 2013). Sugarcane yield is very low in Pakistan and showing the big gap of 4942-7907 kg/ha between actual and potential yield (Nazir *et al.*, 2013).

Impact of climate change on the crop production is studied worldwide, while the studies on the sugarcane crop production are scarce. Marin *et al.* (2013) analyzed the impact of climate change on the attainable yield of sugarcane crop in southern Brazil, a rain-fed based sugarcane cultivated area. DSSAT/CANEGRO model was used for the analysis of the stalk fresh mass and water use efficiency for the base period and for the future scenario. The increase in the rainfall increases the 24% fresh stalk mass and 34% water productivity. Black *et al.* (2012) studied the sugarcane crop under the changing climate in the Ghana. In this study the doubling the CO_2 concentration can mitigate the water stress due to 4°C increase in the temperature. Gawander (2007) studies the impact of climate change on sugarcane in Fiji. Sugarcane being a C4 crop will increase the CO_2 assimilation and causing the increase in the temperature of 8 to 34°C and this increase in the temperature during the winter will increase the cane growth. SWAP can perform analysis of water productivity along with the analysis of the groundwater fluctuation and the behavior of the root zone salt accumulation. Singh *et al.* (2006) performed the water productivity analysis in the irrigated area of the Sirsa district of India. Similarly, the Hadley Centre Coupled Model version 3 (HadCM3) is the well-recognized model for the analysis of climate change at the regional scale. Mahmood *et al.*, (2015) acknowledged the HadCM3 in the assessment of future climate change in the Jhelum river basin of Pakistan. HadCM3 has higher resolution as compared to the other general circulation models (GCM). In this paper, impacts of climate change on sugarcane water productivity was studied from the farmers' fields using soil water atmosphere plant (SWAP) and HadCM3 models.

MATERIALS AND METHODS

***Research fields*:** The research fields are located at the longitude of 72.91° and at the latitude of the 31.41° in the Lower Chenab Canal system. Two fields were selected for the required data collection that are represented as the Sugarcane filed 1 (SC1) and Sugarcane field 2 (SC2). The groundwater quality of the study areas is marginal and soil type is the sandy loam. Research site surface supply is through the Jhang canal that originates from the LCC west.

***Climate change data*:** In this study, Hadley Centre Coupled Model version 3 (HadCM3) was used. Major advantage of the model includes no change in flux and decent simulation of present climate and therefore, in this category it is still highly ranked GCM as compared to other (Reichler and Kim, 2008). It also can capture time reliant pattern of past climate change in reaction to anthropogenic and natural forcing (Stott et al., 2000). Data of HadCM3 were downloaded from the Canadian website, http://www.cics.uvic.ca. The acquired data consist of 26 predictors of National Centers for Environmental Prediction and HadCM3 under both scenarios of A2 and B2 for the duration of 1961-2001 and 1961-2099, respectively. There are two scenarios available in the HadCM3 model for the regional analysis of climate change impact. The scenario A2 represents the regional and uneven economic growth, diverse world with continuously increasing the world population. While the scenario B2 represents the local solution of economic development, social stability, environmental sustainability, continuous population growth but much slower than the A2 scenario and moderate growth of economy.

***Statistical downscaling model*:** Many statistically downscaling (SD) models were developed for downscaling the climatic variables, and their working principal is based on the local/regional information obtained by relating global scale variables of climate like temperature, zonal wind, geo-potential height and pressure on mean sea in relation to the variables at local scale like measured rainfall or temperature. SDSM was used for downscaling of HadCM3 A2 and B2 scenarios for the maximum temperature, minimum temperature and precipitation for the duration of 1960 to 2099 in the LCC command area.

***Selection of predictors*:** In statistical downscaling techniques, important process is the screening of predicator's variables. Several researchers used the P and partial correlation (P.r) values for screening of the variables (Hashmi *et al*., 2011; Huang *et al*., 2011; Mahmood and Babel, 2013).

***Bias correction*:** In this study, bias correction (BC), is also applied to downscaled data obtained from the SDSMs using HadCM3 predictors for more realistic and unbiased data of future climate. For the estimation of mean monthly biases, latest data of minimum temperature, maximum temperature and precipitation data of 1980 to 2010 is used. These biases were then applied with respect to their months on the SDSM based daily downscaled data. The BC method was used for the elimination of the biases from the downscaled data on daily basis (Salzmann *et al.*, 2007). Mathematical representation for the correction of the data based on the estimated biases is given below in equation 1 and 2.

$$T_{corrected} = T_{ScDs} - (\overline{T_{CuDs}} - \overline{T_{Obs}}) \quad (1)$$

$$R_{corrected} = R_{ScDs} \times \left(\frac{\overline{R_{obs}}}{\overline{R_{CuDs}}}\right) \quad (2)$$

Where $T_{corrected}$ and $R_{corrected}$ are future de-biased daily data of temperature and precipitation respectively. ScDs is SDSM based downscaled data for the duration of 2011-2099, and T_{CuDs} and $R_{CuDs}$are SDSM based downscaled data of temperature and rainfall respectively for the base line period 1980-2010. T_{ScDs} and R_{ScDs} are the SDSM based daily data of temperature and precipitation for future periods, respectively. $\overline{T_{CuDs}}$ and $\overline{R_{CuDs}}$ represents the current downscaled (1980-2010) mean monthly values for temperature and precipitation, respectively. $\overline{T_{Obs}}$ and $\overline{R_{Obs}}$ represent the 31 years observed mean monthly values of temperature and precipitation.

SWAP: SWAP is an agro-ecohydrological model that simulates the water and salt transport and crop growth from the field to basin scale. Working principal of the SWAP includes the agro-hydrological process in the band of soil water plant and atmosphere (Kroes and Van Dam, 2003). SWAP was successfully applied in Pakistan under the prevailing irrigation practices (Qureshi and Madramootoo, 2001; Ahmad et al., 2002). It is one dimensional (1D) lumped model and simulates the soil and water flow in vertical direction along with the crop parameters. Transient water flow in SWAP is computed with well-known Richard et al. (1951) equation [3]:

$$C_w(h)\frac{\delta h}{\delta t} = \frac{\partial}{\partial z}[K(h)\left(\frac{\partial h}{\partial z}+1\right) - S_a(z) \ (3)$$

Where, C_w [L^{-1}], h [L], K [LT^{-1}], Sa [T^{-1}] and z [L] represents the differential soil-water capacity, pressure head of soil water, hydraulic conductivity, rate of root water extraction and vertical coordinate, respectively. Positive values of z described the upward movement. The solution of the equation 3 is based on operator identified boundary condition.

Upper boundary condition is based on the potential evapotranspiration (ETp) rate, fluxes of rainfall and irrigation. The estimation of ETp is based on Penman-Monteith equation (Monteith, 1965, 1981; Allen *et al*., 1998). The lower boundary conditions are in the bottom of soil profile based on the water fluxes in soil continuum. In this study free drainage was applied due depth of water table below the 3 m of the soil surface. As, Van dam (200) argued that Darcy's law may possibly overrate the flux of soil evaporation. SWAP has ability to estimate rate of soil evaporation based on the empirical utilities, and calculate the actual evaporation rate using lowest values of maximum evaporation, potential evaporation and empirical based evaporation. In this study following the experience of Singh (2005), the empirical utility of Black *et al.* (1969) was used for the limitation of soil evaporation rate. The actual rate of transpiration depends upon the rate of water extracted by the specific crop and it depends upon the length and distribution of crop root. In this study, root distribution was assumed homogenous over the root length.

In case of too wet, too dry condition and effect of salinity, rate of water extraction reduced to the accrual rate of water extraction. Feddes *et al.* (1978) presented the water stress function. For extreme dry condition, critical pressure head h3 depends upon the Tp. Literature based crop specific input parameters of h1, h2, h3h, h3l and h4 [L] were used for the simulation as given in table 1. While, for salt stress, Maas and Hoffman (1977) described the linear relation for the yield reduction and electrical conductivity of water. Based on the assumption of one to one relationship between the actual transpiration/potential transpiration and actual yield/potential yield, this resulted the salt stress function.

***Water productivity calculation*:** Water productivity is defined as amount of grain yield produced per unit amount of water consumed (Molden, 1997). Different stockholders have different definition of water productivity based on water utilization for the crop production (Molden *et al.*, 2003). These defined water productivity definitions provide the useful indicators for the evaluation of the crop production under the water application and provides the suitable solution to save water at different stages. Methodological frame work is presented in figure 1.

***Input data*:** SWAP parameters can be classified into the soil, crop, initial condition and upper and lower boundaries. Potential evapotranspiration (ETp) rate, fluxes of rainfall and irrigation was used to define the upper boundary condition. In this study, ETp was calculated using the Penman–Monteith equation (Allen *et al.,* 1998). Climatic data obtained from the University of Agriculture, Faisalabad were used during the calibration and validation period, while the impact of climate change was assed using the data derived from the HadCM3 after performing the downscaling and bias correction. Crop specific parameters were calibrated and validated with the field measured values. Qureshi and Madramootoo (2001) presented the pressure head for the sugarcane crop. Detailed parameters of sugarcane crop used are given in Table 1.

Table 1. Input parameters of SWAP.

Parameter	Sugarcane
LCCD	344
MRDCM	175
h1	-1
h2	-5
h3h	-790
h3l	-1000
h4	-16000

LCCD and MRDCM represents crop period in days and maximum rooting depth in cm respectively. While h1 represents no water extraction at higher pressure heads, h2 represents h below which optimum water uptake starts for top layer, h3h represents h below which water uptake reduction starts at high Tpot, h31h below which water uptake reduction starts at low Tpot and h4 represents wilting point, no water uptake at lower pressure heads.

For the simulation, soil depth was considered up to 300 cm and it was divided into three layers. The properties of the last layer were assign to the depth of 300 cm. These soil profiles were further divided into the 40 sub-horizons. For the first ten horizon, nodal distance was fixed 1 cm and for the next 25 it was considered as 5 cm and for the remaining it was 10 cm. This division is acceptable as most of the evaporation takes place in the upper few centimeters of the soil (Van Dam and

Feddes, 2000; Singh *et al.*, 2006). Further, a factor of 0.35 (cm d^{-1}) was used for the limitation of soil evaporation along with Darcy's law (Black *et al.*, 1969), dispersion length of 5 cm was set for the salute transport in the irrigated field (Singh *et al.*, 2006).

***Optimized soil hydraulic parameters*:** Vertical soil column was divided into 40 sections and differentiated into three depth and different soil hydraulic properties. At each depth specified soil hydraulic functions are required. These functions show the association between soil metric head h_m, hydraulic conductivity and soil moisture content θ and were described by the Van Genuchten-Mualem parameters (Wosten *et al.*, 1998; Van Genuchten, 1987).

Inverse modelling was performed for the automatic calibration of the model. For this purpose, SWAP was linked with parameter estimation technique (PEST), PEST is a non-linear parameter assessment package (Doherty *et al.*, 1995). PEST uses a nonlinear estimation technique and requires reliable measured other inputs and field observations for accurate estimation of soil hydraulic parameters. Further, the selection of the parameters which are optimized, should be necessarily sensitive to the observed field's measurements. In this study for the calibration of the soil hydraulic parameters, observed soil moisture and root zone salinity were used.

From the parameters describing the soil hydraulic functions Θ_{sat}t (cm^3 cm^{-3}) and K_{sat} (cm d^{-1}) have a clear physical meaning and was measured directly from the corresponding field. The Θ_{res} (cm^3 cm^{-3}) and empirical shape parameter λ [–] are fewer sensitive to water and salt transport (Singh, 2005). Therefore, the remaining two parameters were optimized that are ∝ (cm^{-1}) and n

[–]. In optimization process, objective function estimates the variances among observation and model simulation. If the observation errors obey multivariate standard scattering with zero mean, not any correlation, each observation shows fixed variance, expansion of likelihood by repeating the measured information directed to the weighted least squares objective function Φ (b) as given in equation (4):

$$\emptyset\,(b) = \sum_{i=1}^{N}\Big[\big\{W_o\big(\theta_r(t_i)\big) - \theta_s(b,t_i)\big\}^2 + \big\{W_{EC}\big(EC_r(t_i) - EC_s(b,t_i)\big)\big\}^2\Big] \qquad (4)$$

where $\theta_r(t_i)$ and $EC_r(t_i)$ are the measured root zone salinity and soil moisture at time *ti* , *N* represents the total number of measurements, $\theta_s\,(b,t_i)$ and $EC_S\,(b,t_i)$ represents the simulated values of θ and EC using an array with parameter values b. W_O and W_{EC} represents the weight related to θ_{Obs} and EC_{Obs}, respectively.

***Accuracy assessment*:** Calibration and validation was performed in the Rabi season due to the detail monitoring of farmer's fields. Calibration was performed for the period of sowing to mid of February and validation was performed for the period of mid-February to the end of crop harvest. Root mean square error (equation 5) is useful statistical indicator for the quantification of accuracy between the measured and simulated values.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}[Mesured(t_i) - Simulated(t_i,b)]^2} \quad (5)$$

Where, $Measured(t_i)$ is the measured and $Simulated\,(t_i,b)$ is simulated values at time t_i, and N represents the total numbers of measurements.

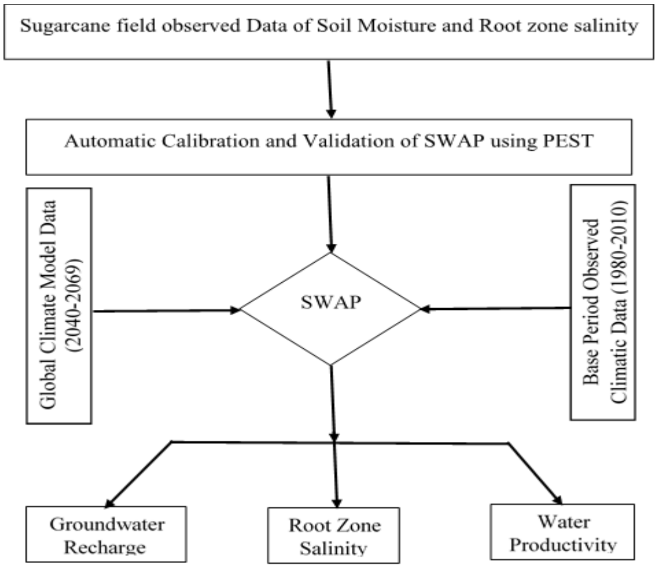

Figure 1. Flow diagram of the methodology.

RESULTS AND DISCUSSION

The measured soil moisture and root zone salinity were used for the optimization of soil hydraulic parameters with automatic calibration using PEST. PEST inverse solution optimized n and α for all the soil layers under investigation. Uniqueness of the solution is done when iteration in inverse solution with altered initial limits of n and α ensued the unchanged values (Singh *et al*, 2006). Table 2 shows the optimized values of α and n along with Ks, θs and θr.

Table 2. Optimized soil hydraulic parameters for sugarcane fields.

Field	SC1			SC2		
Soil type	**SL**	**SL**	**SL**	**SL**	**SL**	**SL**
Depth	0-30	30-60	60-120	0-30	30-60	60-120
Θr	0.000	0.010	0.000	0.000	0.010	0.010
Θs	0.430	0.330	0.440	0.380	0.330	0.330
Ks	20.00	49.58	44.50	33.50	49.58	49.58
α	0.030	0.046	0.026	0.010	0.046	0.046
λ	-1.40	-1.58	-1.49	-1.54	-1.54	-1.58
n	1.44	1.54	1.56	1.53	1.58	1.61

Calibration and validation of SWAP**:** Calibration was performed for the period of sowing to June and validation was performed for the period of June to the end of crop harvest. Figure 2 shows the simulated and measured pattern of soil moisture and salinity during calibration and validation period respectively. The RMSE of the moisture contents and root zone salinity is given in Table 3.

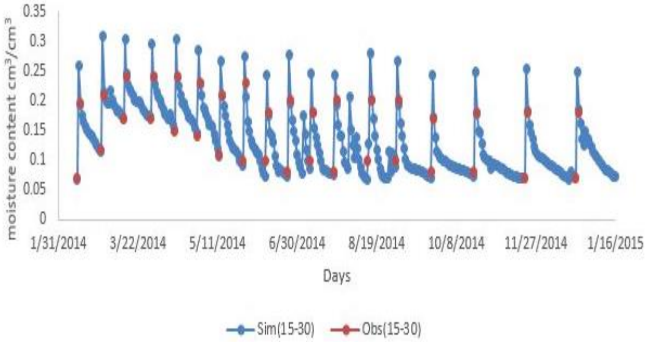

Figure 1(a). Observed vs simulated soil moisture during calibration and validation at depth of 15-30 cm.

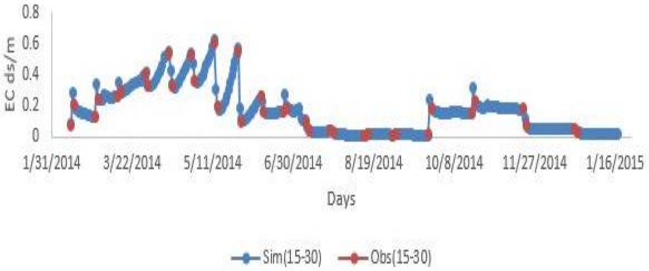

Figure 2(b). Observed vs simulated EC at depth of and 15-30 cm.

Table 3. Statistical analysis of SWAP model during calibration and validation for research sites.

Research Site	Calibration		Validation		Calibration		Validation	
	θ (cm^3 cm^{-3})				EC1:2 (dSm^{-1})			
	N	RMSE	N	RMSE	N	RMSE	N	RMSE
SC1	16	0.028	12	0.023	16	0.24	12	0.28
SC2	16	0.026	12	0.026	16	0.26	12	0.32

Future climatic data under A2 and B2 scenario**:** Predictor was selected based on mean absolute partial correlation (P.r) for climatic parameters under study with the significance level of 0.05. It was observed that temperature is the super predictor in case of $\boldsymbol{T_{min}}$ and $\boldsymbol{T_{max}}$, while for rainfall, surface specific humidity was found asper predictor. Super predictor has the highest correlation with predictand under study. These predictor shows higher resemblance with other studies (Chu *et al.*, 2010; Hashmi *et al.*, 2011; Mahmood and Babel, 2013). These predictors are used for the achievement of enhanced results in the SDSM.

The explained variance of precipitation is much lower than temperature. Wilby *et al.* (2002) and Mahmood *et al.* (2015) argued that it is difficult to accurately simulate the precipitation due its heterogeneity as compared to other climatic variables.

Bias correction**:** Bias correction technique was applied on downscaled data to increase accuracy in the predicted data. Application of BC improves the results of calibrated SDSM predicted results, as Mahmood and Babel (2013) found much improvement in results, especially in case of precipitation. In midcentury, increase in maximum and minimum temperature was found 5.2 and 10.3% respectively under A2 scenario, while under B2 scenario, maximums and minimum temperature increase for the midcentury was found 4.4 and 9.0%, respectively. Both scenarios showed decrease in rainfall, under A2 it was found -0.1% and under B2 it was found -1.4%. Figure 2 represents the rainfall under A2 and B2 scenario.

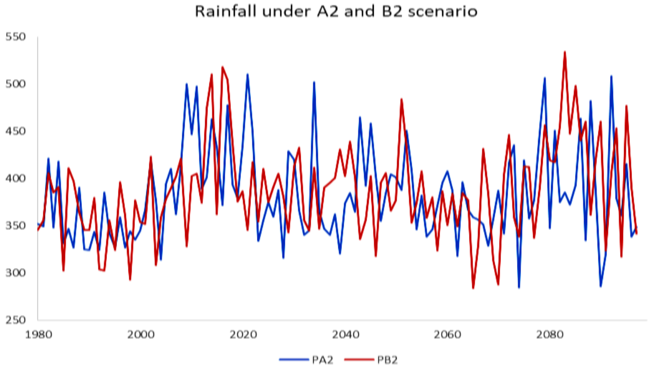

Figure 2. Rainfall under A2 and B2 scenario.

Climate induced groundwater recharge and root zone salinity built up**:** Optimized soil hydraulic parameters along with crop data were used in SWAP for the simulation of salt and water balance. Groundwater recharge variation for the base line period was found significant. The negative values indicate the depletion of aquifer. Maximum depletion in aquifer was found during the base period in both fields. Awan and Ismaeel (2014) found the increase in groundwater recharge in the same study area under changing climate due to 70% increase in the rainfall under representative concentration pathways (RCP) 4.5 scenario and 75% increase under RCP 8.5 scenario. Salt accumulation was found in the reverse order of groundwater recharge situation. For the midcentury under A2 scenario, groundwater recharge was found higher. Groundwater recharge for the midcentury was increased as compared to the base period mean recharge and less depletion in the aquifer was found. This increase in rainfall causes the reduction in mean salt accumulation as compared to its base period. Shah *et al.* (2011) determined the behavior of the root zone salt accumulation under different climatic condition and found the salt depletion under wet climate. Kijne *et al.* 2006 argued that the extra amount of the water is also required to leach down the root zone salt. In this study, leaching of the salts is due to the increase in the rainfall. Similarly, under the B2 scenario, more increase increased in rainfall as compared to A2 scenario, increases groundwater recharge and causes the reduction in the root zone salt accumulation. Detail of groundwater recharge and root zone salt accumulation is given in Table 4.

Table 04. Simulation of groundwater recharge and root zone salinity built up.

Sugarcane	SC1	SC2	SC1	SC2	SC1	SC2
Fields	Base Period		A2 Scenario		B2 Scenario	
GWr (mm)	-142	-143	-121	-124	-117	-120
dC (mg cm^{-2})	28	21	26	19	27	21

GWr is groundwater recharge and its negative value indicates depletion of aquifer and dC is the change in root zone salts.

Climate induced water productivity: Climate induced water productivity of sugarcane was analyzed using SWAP model. Different researchers analyzed the water productivity in different region of the world. Global bench mark was presented by Zwart and Bastiaanssen (2004) based on the available review of literature from the last 2.5 decades experiments. Usman *et al.* (2012) found the groundwater productivity of sugarcane 3.51 to 8.50 kgm^{-3} in Rechna Doab. Ashraf *et al.* (2010) found the water productivity of sugarcane 1.08 to 2.01 kgm^{-3} during the evaluation the lower Bari Doab existing water productivity. Table 5 shows the similar findings of water productivity during the base period according to studies aforementioned. Water productivity analysis during the midcentury shows reduction in water productivity due to climate change impact. This reduction was increase in the intensity of the rainfall that increase the amount of water available to the fields without its proper requirements. This untimely water supply causes the reduction in the water productivity. On this fact in other way, Singh et al. (2006) argued that decreasing the denominator or reduction in the seepage losses will increase the water productivity. This reduction was due to increase in temperature that increases the evapotranspiration from the fields. Increase in the denominator reduced the water productivity of the system. More reduction in water productivity was observed under B2 scenario as compared to A2 scenario from the base period analysis. Table 5 represents the detail description of water productivity analysis at the different scale of water use for the evaluation of maximum potential of water productivity for the base line, A2 and B2 scenario in sugarcane fields. The difference is much higher due to water losses under traditional irrigation practices in the water productivity from the evapotranspiration based to the applied water.

Table 5. Water productivity analysis for base line period (1980-2010).

Sugarcane	SC1	SC2	SC1	SC2	SC1	SC2
Water Productivity	Base Period		A2 Scenario		B2 Scenario	
WPT	6.1	6.3	5.6	5.8	5.4	5.6
WPET	5.2	5.2	4.7	4.8	4.4	4.5
WPI	3.9	4.0	3.4	3.6	3.2	3.4

WPT is the yield over transpiration, WPET is the yield over evapotranspiration and Yield over Water Applied

***Conclusion*:** Impact of climate change based on the selected model showed increasing trend of groundwater recharge and subsequently dilution of the root zone salt accumulation. While the climate induced water productivity depicted decreasing trend, which directs the need of efficient water management according to the seasonal variation of the rainfall. There should be proper irrigation scheduling under high efficiency irrigation system which will no doubt increase the water productivity but will also control the externalities in terms of environmental degradation due to salt accumulation. It means there is tradeoff between salt leaching and accumulation under flood irrigation and high efficiency irrigation system respectively. Keeping in view the pros and cons of traditional and pressurized irrigation an optimum point of water use efficiency and threshold level of flushing salts should be established for sustainable soil and water productivity on longer term.

REFERENCES

Ahmad, M.U.D., W. Bastiaanssen and R. Feddes. 2002. Sustainable use of groundwater for irrigation: a numerical analysis of the subsoil water fluxes. Irrig. Drain. 51:227-241.

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome 300:D05109.

Ashraf, M., A. Nasir and M. Saeed. 2010. Evaluation of the existing water productivity in the lower Bari Doab Canal (LBDC) command- A case study. Pak. J. Agri. Sci. 47:389-397.

Black, E., P.L. Vidale, A. Verhoef, S.V. Cuadra, T. Osborne and C. Van Den Hoof. 2012. Cultivating C4 crops in a changing climate: sugarcane in Ghana. Environ. Res. Lett. 7:044027.

Black, T., W. Gardner and G. Thurtell. 1969. The prediction of evaporation, drainage, and soil water storage for a bare soil. Soil Sci Soc. Am. J. 33:655-660.

Chu, J., J. Xia, C.Y. Xu and V. Singh. 2010. Statistical downscaling of daily mean temperature, pan evaporation and precipitation for climate change scenarios in Haihe River, China. Theor. Appl. Climatol. 99:149-161.

De Souza, A.P., M. Gaspar, E.A. Da Silva, E.C. Ulian, A.J. Waclawovsky, R.V. Dos Santos, M.M. Teixeira, G.M. Souza and M.S. Buckeridge. 2008. Elevated CO2 increases photosynthesis, biomass and productivity, and modifies gene expression in sugarcane. Plant Cell Environ. 31:1116-1127.

Doherty, J., L. Brebber and P. Whyte. 1995. PEST. Model Independent Parameter Estimation, Australian Centre for Tropical Freshwater Research. James Cooke University, Townsville, Australia.

Feddes, R., P. Kowalik and H. Zaradny. 1978. Simulation of field water use and crop yield. Simulation Monograph. Pudoc for the Centre for Agricultural Publishing and Documentation, Wageningen, Netherland.

Gawander, J. 2007. Impact of climate change on sugar-cane production in Fiji. WMO Bull. 56:34-39.

Government of Pakistan. 2016. Pakistan Economic Survey 2015-16. Finance Division, Ministry of Finance, Islamabad, Pakistan.

Government of Canada. Available online at http://climate-scenarios.canada.ca/?page=pred-hadcm3.

Kijne, J. 2006. Salinization in irrigated agriculture in Pakistan: Mistaken predictions. Water Policy 8:325-338.

Khan, S., R. Tariq, C. Yuanlai and J. Blackwell. 2006. Can irrigation be sustainable? Agric. Water Manage. 80:87-99.

Hashmi, M.Z., A.Y. Shamseldin and B.W. Melville. 2011. Statistical downscaling of watershed precipitation using Gene Expression Programming (GEP). Environ. Modell. Softw. 26:1639-1646.

Huang, J., J. Zhang, Z. Zhang, C. Xu, B. Wang and J. Yao. 2011. Estimation of future precipitation change in the Yangtze River basin by using statistical downscaling method. Stoch. Environ. Res. Risk Assess. 25:781-792.

Maas, E.V. and G.J. Hoffman. 1977. Crop salt tolerance–current assessment. J. Irrig. Drain. Div. 103:115-134.

Mahmood, R. and M.S. Babel. 2013. Evaluation of SDSM developed by annual and monthly sub-models for downscaling temperature and precipitation in the Jhelum basin, Pakistan and India. Theor. Appl. Climatol. 113:27-44.

Mahmood, R., M.S. Babel and J. Shaofeng. 2015. Assessment of temporal and spatial changes of future climate in the Jhelum river basin, Pakistan and India. Weather Clim Extrem. 10:40-55.

Marin, F.R., J.W. Jones, A. Singels, F. Royce, E.D. Assad, G.Q. Pellegrino and F. Justino. 2013. Climate change impacts on sugarcane attainable yield in southern Brazil. Climate Change 117:227-239.

Molden, D. 1997. Accounting for water use and productivity, IWMI. Sri Lanka.

Molden, D., H. Murray-Rust, R. Sakthivadivel, and I. Makin. 2003. A water-productivity framework for understanding and action. IWMI, Sri Lanka..

Nazir, A., G.A. Jariko and M.A. Junejo. 2013. Factors affecting sugarcane production in Pakistan. Pak. J. Commer. Soc. Sci. 7:128-140.

Qureshi, S. and C. Madramootoo. 2001. Modelling the soil water balance of a sugarcane crop in Sindh, Pakistan with SWAP93. Can. Water Resour. J. 26:129-150.

Reichler, T. and J. Kim. 2008. How well do coupled models simulate today's climate? Bull. Am. Meteorol. Soc. 89:303-311.

Rosenzweig, C., J.W. Jones, J.L. Hatfield, A.C. Ruane, K.J. Boote, P. Thorburn, J.M. Antle, G.C. Nelson, C. Porter and S. Janssen. 2013. The agricultural model intercomparison and improvement project (AgMIP): protocols and pilot studies. Agric. For. Meteorol. 170:166-182.

Salzmann, N., C. Frei, P.-L. Vidale and M. Hoelzle. 2007. The application of Regional Climate Model output for the simulation of high-mountain permafrost scenarios. Glob. Planet Change 56:188-202.

Shakoor, A., Z.M. Khan, H.U. Farid, I. Ahmad, N. Ahmad, M. Nadeem, M.U. Ali and F. Baig. 2018. Delineation of regional groundwater vulnerability and determining its impact on agricultural productivity. J. Glob. Innov. Agric. Soc. Sci. 6:47-53.

Singh, R., J. Van Dam and R. Feddes. 2006. Water productivity analysis of irrigated crops in Sirsa district, India. Agric Water Manage. 82:253-278.

Shah, S., R. Vervoort, S. Suweis, A. Guswa, A. Rinaldo and S. Van Der Zee. 2011. Stochastic modeling of salt accumulation in the root zone due to capillary flux from brackish groundwater. Water Resour. Res. 47:1-17

Stott, P.A., S. Tett, G. Jones, M. Allen, J. Mitchell and G. Jenkins. 2000. External control of 20th century temperature by natural and anthropogenic forcings. Sci. 290:2133-2137.

Trenberth, K.E., P.D. Jones, P. Ambenje, R. Bojariu, D. Easterling, A. Klein Tank, D. Parker, F. Rahimzadeh, J.A. Renwick, M. Rusticucci, B. Soden and P. Zhai. 2007. Observations: Surface and atmospheric climate change. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Usman, M., I. Kazmi, T. Khaliq, A. Ahmad, M. Saleem and A. Shabbir. 2012. Variability in water use, crop water productivity and profitability of rice and wheat in Rechna Doab, Punjab. J. Anim. Plant Sci. 22:998-1003.

Van Dam, J.C. and R.A. Feddes. 2000. Numerical simulation of infiltration, evaporation and shallow groundwater levels with the Richards equation. J. Hydrol. 233:72-85.

Van Genuchten, M.T. 1987. A numerical model for water and solute movement in and below the root zone, United States Department of Agriculture Agricultural Research Service US Salinity Laboratory, USA.

Wilby, R.L., C.W. Dawson and E.M. Barrow. 2002. SDSM-a decision support tool for the assessment of regional climate change impacts. Environ. Modell. Softw. 17:145-157.

Wösten, J., A. Lilly, A. Nemes and C. Le Bas. 1998. Using existing soil data to derive hydraulic parameters for simulation models in environmental studies and in land use planning. DLO-Staring Centre, Wageningen, Netherland.

Zwart, S.J. and W.G. Bastiaanssen. 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric. Water Manage. 69:115-133.