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Climate Change Impact on Hydrologic System in Aji River Basin

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Abstract

The CCAM (GFDL) RCM simulated daily maximum/minimum temperature and rainfall datafor the base line period (1970-2005) and future scenario (2006-2070) for the IPCC SRES rcp 4.5 for 4 grid points (50kmx50km) falling in Aji basin were bias corrected using Probability Distribution Mapping adopting Gaussian and Gamma distribution respectively. The warming trend of annual average of daily minimum and maximum temperature from 1970-2005 to 2006-2070 was found increased from 0.027°C year^{-1} to 0.04°C year^{-1} and 0.027°C year^{-1} to 0.025°C year^{-1} respectively. The rainfall, runoff and groundwater recharge in the basin were found in statistically stable trend in Aji basin. The best probability distribution was used for estimating each water balance component. The crop water requirements during winter, summer and monsoon season may increase/decrease by the tune of 6.4%, - 0.3% and 1.5% during winter, summer and monsoon season respectively in the future as compared to the past, due to climate change impacts. The monsoon seasonal rainfall will be decreased in the future due to climate change impacts. However, the extreme rainfall (100 year return period) event will be increased in the future by the tune of 39%. Similarly, the runoff will be decreased in the future but the extreme event (100 year return period) of runoff will be increased by the tune of 87.5%. The extremity (100 year return period) in the crop evapotranspiration and ground water recharge may be decreased by -5.7% and -5.8% respectively.

1. Introduction

Water resources of the planet Earth take part in the infinitely recurrent hydrological cycle, the largest movement of matter in the Earth's system. Since water is the basic element of the life support system of the planet, it is of utmost importance to understand the impacts of the ongoing and projected climate change on water resources and water availability. Under balance of evidence, global warming is unequivocal and most of it is very likely due to the increase in atmospheric greenhouse gas concentrations. Observed climate change has extended beyond temperature. The likelihood of deleterious impacts, as well as the cost and difficulty of adaptation, would increase with the extent and the speed of global climate change. One of the effects of climate change is that hydrological extremes become more extreme. This leads to emergence of hot-spots and vulnerable areas, and the need for difficult adaptation. Globally, the negative impacts of climate change on freshwater systems are very likely to outweigh their benefits (Kundzewicz, 2008). Therefore, the study was planned with the objectives to prepare the various thematic maps, assess the different hydrological balance using SWAT modelling, analyze the probability of water balance components and assess the climate change impacts on water resources of the basin.

2. Materials and Methods

The CCAM (GFDL) RCM simulated daily maximum/minimum temperature and rainfall data(50kmx50km) for the base line period (1970-2005) and future scenario (2006-2070) for the IPCC SRES rcp 4.5 for 4 grid point falling in Aji basin were taken from the IITM, Pune. Conformal-Cubic Atmospheric Model (CCAM) RCM is a recent earth-system model developed by a Consortium of Common Wealth Scientific and Industrial Research Organization (CSIRO), (McGregor and Dex, 2001) run under the experiment named as CCAM (GFDL), based on state-of-the-art models for the atmosphere, the ocean, sea ice and the biosphere. In particular, the model is based on the concept of "seamless predictions": numerical weather prediction (NWP) models are sophisticated state-of-the art models which, being based on the same physical principles, may provide advanced atmospheric components for climate models. The CCAM RCM data were driven by the GFDL-CM3 GCM. The software namely (a) Remote sensing and GIS software –Arc GIS V10.1, (b) Remote sensing and GIS software

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– PCI GEOMETICA V10.1, (C) Arc SWAT 2012 and (D) WGEN maker 4.1 were used.

The RCM simulated weather data were bias corrected and used as SWAT inputs as well as for the analysis. The digital data namely Map of India, Map of Gujarat, Map of Watershed, Cadastral map of river basins of Jamnagar district, Satellite images of IRS P6 of sensor LISS III and 90m SRTM DEM were collected from BISAG, Gandhinagar and used in this study. The water table data records (1969-2010) before and after monsoon for the different gauge stations of the study area with aquifer properties were collected from the Central Groundwater Board, Ahmadabad.

The daily maximum/minimum temperature and rainfall for the 4 grid points-P1 (70.49E and 21.99N), P2 (70.49E and 22.49N), P3 (70.99E and 21.99N) and P4 (70.99E and 22.49N) falling in Aji basin simulated by CCAM RCM during the baseline period were compared with observation during the past (1970-2005) and were bias corrected using probability distribution mapping for the periods of base line (1970-2005) and future periods (2006-2070) for the rcp 4.5 SRES scenario.

The CCAM (GFDL) RCM simulated daily maximum/minimum temperature and rainfall data (50 kmx50km) for the base line period (1970-2005) and future scenario (2006-2070) for the IPCC SRES rcp4.5 for 4 grid point falling in Aji basin were bias corrected using Probability Distribution Mapping adopting Gaussian and Gamma distribution respectively.

2.1. Estimation of water balance components of SWAT model

The water balance components like runoff, evapotranspiration and groundwater recharge was estimated through the SWAT model simulation using the bias corrected simulated daily data of maximum and minimum temperature and rainfall simulated by CCAM (GFDL-CM3) RCM. The SWAT model was also run for the future scenario of the weather after calibration and validation. Data used for setting up the SWAT model for the river basin included a digital elevation model (DEM), soil and land-use maps, data on soil properties, climate, reservoir, and management.

2.2. SWAT hydrology

Similar to most river basin models, SWAT is driven by the water balance of a river basin. The simulation of a basin's hydrology can be separated into (i) the land phase of the hydrologic cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin, and (ii) the routing phase of the hydrologic cycle, which is the movement of water, sediments, etc., through the channel network of the basin to the outlet (Neitsch *et al.,* 2005). Irrespective of the problem studied in a river basin, predictions made with SWAT can only be accurate if the model is able to mimic the hydrologic cycle in the basin. The hydrologic cycle that takes place in a basin is explained by the water balance in the basin. The water balance equation that represents the hydrologic cycle simulated in SWAT can be expressed mathematically as (Neitsch *et al.,* 2005):

$$sw_t = sw_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where: SW_t is the soil water content at time t (mm); SW_0 is the initial soil water content on the day i (mm); t is time (days); R_{days} is the amount of precipitation on the day i (mm); Q_{surf} is the is the amount of surface runoff on day i (mm); E_a is the amount of evapotranspiration on day i (mm); W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm); and Q_{gwis} the amount of return flow on day i (mm). In SWAT, most of the hydrologic processes take place at the HRU level, and the water balance is simulated at this level before runoff is routed to the reaches of sub basins and then to the basin channel. The major hydrologic components modelled in SWAT as depicted in the water balance equation are precipitation, surface runoff, evapotranspiration, infiltration, groundwater flow and soil water content. The calibration of the SWAT model was done using observed data of weather and runoff of 12 years. The calibrated SWAT model was validated using observed data of 7 years. It is a continuous time series model with a GIS interface and that uses readily available input data. SWAT has proven to be an effective model for river basin studies under different environmental and climatic conditions. (Arnold and Allen, 1996).

The water balance components were computed using SWAT model. Time series of bias corrected temperature and rainfall along with each water balance component were analyzed graphically and M-K test statistics (Mann, 1945; Kendall, 1975; Gilbert, 1987).

2.3. Probability distributions

The data series of reference evapotranspiration of past and future annual, winter, summer and monsoon periods as well as water balance components during monsoon season like rainfall, runoff, crop evapotranspiration, and groundwater recharge for the past and future periods were analyzed for the probability distribution. The performance indices like Mean Absolute Differences between calculated and observed frequencies (%), efficiency coefficient (R) of calculated and observed cumulative frequency as well as efficiency coefficient (R) of calculated and observed data values were compared and best fit probability distribution was proposed for each time series data.

3. Results and Discussion

The bias correction of RCM simulated data of temperature and rainfall were done using the distribution mapping and fed to SWAT model and water balance was assessed. The calibration and validation of the SWAT model was made using observed data.

3.1. Rainfall

The CCAM (GFDL) RCM simulated daily rainfall data for future period 2006-2070 were bias corrected using Gamma distribution parameters of observed and RCM simulated daily rainfall data of calibration period (1970-1995) of control period (1970-2005). The monthly average of raw and bias corrected rainfall data simulated by RCM for the future scenario-2006-2070 showed that the bias corrected rainfall was found increased over uncorrected data during June to September, while decreased in May, October and November month. During rest of the months, the simulated rainfall was found lower and not differed much. The coefficient of variation of raw and bias corrected daily rainfall showed that the CV of raw simulated data was much higher. In fact, after bias correction it was reduced except in September. The annual as well as seasonal rainfall of winter, summer and monsoon seasonal rainfall averaged for the period 1970-2005, 2006-2040 and 2041-2070 showed that the annual average of rainfall in Aji basin during 1951-2005, 2006-2040 and 2041-2070 can be 572 mm, 392 mm and 430 mm respectively. It can also be seen that the average of annual and monsoon rainfall decreases from 1970-2005 to 2006-2040 and again increases during 2041-2070. The Man-Kendall and Sens slope statistics were carried out for the monsoon and annual rainfall for the time series of 1970-2005 and 2006-2100 (Table 1) in the Aji basin. The results showed that there was a stable trend of rainfall during the past and in the future also, the rainfall will remain stable. There is no definite trend in times series of rainfall in Aji basin even though the warming trend exists. However, Singh (1999) found that an increasing linear trend was observed in the rainfall for the Luni river basin of north-west arid India. Rupakumar and Ashrit (2001) have projected 13% increase in monsoon rainfall in India using ECHAM4 model (Table 1).

Table 1: Trend statistics of rainfall for the past (1970-2005) and future (2006-70)

Period	Season	Man-Kendall (Z)	Sens slope	1% level		5% level		Rainfall Trend
				Lower	Upper	Lower	Upper	
			Mm year^{-1}	Mm year^{-1}	Mm year^{-1}	Mm year^{-1}	Mm year^{-1}	Mm year^{-1}
1970-2005	Annual	0.56NS	-2.99	-21.41	9.42	-15.94	6.23	stable
	Monsoon	0.53NS	-3.08	-20.22	9.49	-16.26	6.23	stable
1970-2005	June	0.22NS	0.00	-3.33	4.32	-2.23	2.04	Stable
	July	-1.72**	-3.22	-13.61	1.47	-10.62	0.31	Stable
	Aug.	-0.16NS	-0.58	-7.53	5.68	-5.60	4.42	Stable
	Sept.	-0.57NS	-0.33	-1.94	1.39	-1.36	0.77	Stable
	Oct.	0.00	0.00	0.00	0.00	0.00	0.00	Stable
2006-2070	Annual	1.01NS	1.32	-2.11	4.85	-1.29	3.94	stable
	Monsoon	1.08NS	1.43	-2.05	4.49	-1.16	3.68	stable
2006-2070	June	0.51NS	0.00	-0.22	0.34	-0.04	0.18	Stable
	July	-0.30NS	0.00	-0.39	0.27	-0.22	0.09	Stable
	Aug.	-1.23NS	-0.61	-1.88	0.80	-1.59	0.36	Stable
	Sept.	0.89NS	0.34	-0.63	1.40	-0.41	1.08	Stable
	Oct.	0.95NS	0.00	-0.04	0.21	0.00	0.16	Stable

3.2. Runoff

The SWAT model was run for the 12 year and 7 years for the calibration and validation respectively for the observed weather inputs and the runoff was obtained and compared. It was found that during the calibrated data, the computed runoff data was matched well with the observed data with R2 of 0.97. During the calibration, the SWAT computed runoff was matched with observed runoff with R2 of 0.76. It indicated that the SWAT model simulate the runoff comparable to observed runoff from Aji basin. The monsoon seasonal runoff was found as 261 mm, 187 mm and 182 mm respectively during 1970-2005, 2006-2040 and 2041-2070. The time series of seasonal and annual runoff were obtained through SWAT model for inputs of bias corrected RCM simulated daily precipitation, maximum and minimum temperature for the period 1970-2070 as well as digital image of land use, soil and DEM of the Aji basin. The decadal average of monsoon seasonal and annual runoff was obtained using times series of runoff (1970-2070). It can be seen that monsoon seasonal runoff increases from 1971-80 to 1981- 90, 2001-10 to 2011-20 and 2041-50 to 2051-60 whereas found decreasing for the decade from 1981-90 to 2001-10, 2011-20 to 2041-2050 and 2051-60 to 2061-70. The Mann-Kendall and Sens slope statistics of the times series data of monsoon runoff were carried out separately for the past (1970-2005) and future (2006-2070) and the trend was found stable as shown in Table 2. The Figur 1 shows that the runoff during monsoon season was found stable. The Table 2 also shows that the runoff trend was stable in the past (1970-2005) and will also be stable in the future (2006-2070).

The results indicate that the runoff from the basin will not be impacted by climate change. However,Gosain *et al.* (2006) reported that by 2050s, the quantity of surface run off due to climate

change would decrease. Subtle changes have already been noted in the monsoon rain patterns by scientists at IIT, Delhi. They also warn that by the 2050s, India will experience a decline in its summer rainfall, which accounts for almost 70 per cent of the total annual rainfall and is crucial to agriculture. Many parts of peninsular India, especially the Western Ghats, are likely to experience a 5–10% increase in total precipitation (IPCC, 2007); however, this increase is likely to be accompanied by greater temporal variability. The trend may reflect a continuation of some past trends. Increased frequency of extremely wet rainy seasons (Gosain and Rao, 2007) is also likely to mean increased runoff. According to Milly *et al.* (2005), compared to 1900–1970, most of India is likely to experience 5–20% increase in annual runoff during 2041–60.

Table 2: Man-Kendall and Sens slope statistics of monsoon seasonal runoff in past and future

Period	Man-Kendall (Z)	Sen's	1% level		5% level	
			Lower	Upper	Lower	Upper
1970-2005	0.42NS	-1.27	-12.45	6.33	-9.99	4.25
2006-2070	0.62NS	0.27	-0.99	1.55	-0.67	1.16

3.3. Reference evapotranspiration

The Mann-kendall and Sens slope statistics of the times series data of reference Evapotranspiration (ET_o) was carried out separately for the past (1970-2005) and future (2006-2070) and was found as shown in Table 3. It can be seen in Table-3 that the average annual reference evapotranspiration is increasing from 1970 to 2070 and found as 1964 mm, 1996 mm, and 2010 mm respectively during the period 1970-2005, 2006-2040 and 2041-2070 respectively. Similarly, it was 438 mm, 458 mm and 475 mm in winter season, 700 mm, 698 mm and 698 mm in summer season and 826 mm, 839 mm and 837 mm in monsoon season during the period 1970-2005, 2006-2040 and 2041-2070 respectively. The reference evapotranspiration during monsoon season is higher than summer season because of more number of considered months of monsoon season (June to October). The monsoon, winter and summer season were considered from 1st June to 31st October, 1st November to 15th Feb and 16th Feb. to 31st May for monsoon, winter and summer season respectively.

Table 3 shows that the overall trend of reference evapotranspiration-ET_o is increasing during all three seasons. The increasing rate of reference evapotranspiration-ET_o during annual, winter, and summer season is 160 mm century^{-1}, 43 mm century^{-1} and 103 mmcentury^{-1} with goodness of fit of 0.40, 0.29 and 0.34 respectively. However, the trend of ET_o during the monsoon season was found stable for the period-1970-2005. The Maan-Kendall statistics (Table-6b) showed that the increasing trend was significant at 5% for annual and 10% significant level for Summer and Monsoon season.

The reference evapotranspiration-ET_o would be stable during the Summer and Monsoon seasons for the period 2006-2070. It also shows that the reference evapotranspiration-ET_o is increasing continuously for the winter season from the decade 2011 to 2060, then slightly reduces for decade 2061-70. The increasing rate of reference evapotranspiration-ET_o during winter season is 41 mmcentury^{-1} with goodness of fit of 0.61, while stable trend found for the monsoon and summer season during the period of 2006-70.The Maan-Kendall statistics (Table-3b) showed that the reference evapotranspiration-ET_o will be increasing significantly at 0.1% for winter, while stable trend for summer and monsoon season. The Sens slope statistics also supported the Maan-Kendall statistics for the winter season.

The average annual reference Evapotranspiration was found as 1963 mm and 2002 mm respectively during the past (1970-2005) and future (2006 to 2070). Similarly, it was 438mm and 466 mm in winter, 700 mm and 698 mm in summer and 826 mm and 838 mm in monsoon season during the past (1951-2005) and future (2006-2100). (Table 3a). The reference evapotranspiration increases at 57 mmcentury^{-1} and 51 mm century^{-1} with goodness of best fit as 0.35 and 0.80 for annual and winter respectively during the period 1970-2070. No trend was found in reference evapotranspiration during summer and monsoon season.

The variation of decadal average of evapotranspiration-ET during monsoon. It can be seen that the overall trend of evapotranspiration seemed decreasing from 1970 to 2005. The Table 4 shows that the decreasing rate of evapotranspiration-

Table 3a: Average reference evapotranspiration in different seasons during past (1970-2005) and future (2006-70)

Periods	Reference Evapotranspiration(mm) duringseason							
	Annual (1st Jan. to 31st Dec., 365 days))		Winter (1st Nov. to 15th Feb., 105 days))		Summer (16th Feb. to 31st May, 107 days)		Monsoon (1st June to 31st October, 153 days)	
	mm season^{-1}	mm day-1	mm season^{-1}	mm day^{-1}	mm season^{-1}	mm day^{-1}	mm season^{-1}	mm day^{-1}
1970-2005	1964	5.38	438	4.17	700	6.54	826	5.40
2006-2040	1996	5.47	458	4.36	698	6.52	839	5.48
2041-2070	2010	5.51	475	4.52	698	6.52	837	5.47
2006-2070	2002	5.48	466	4.44	698	6.52	838	5.48

Table 3b: Maan-Kendall and Sens slope statistics of the seasonal reference evapotranspiration (ETo) during the past (1971-2005) and future (2006-2070)

Period	Season	Best fit Trend slope	R^2	Man-Kendall (Z)	Sens slope	1% level		5% level		ET_o Trend
						Lower	Upper	Lower	Upper	
		mm year^{-1}			mm year^{-1}	mm year^{-1}	mm year^{-1}	mm year^{-1}	mm year^{-1}	
1971-2005	Annual	1.60	0.39	1.95**	1.81	-0.84	4.23	-0.02	3.46	Increasing
	Winter	0.43	0.28	1.16NS	0.48	-0.59	1.33	-0.30	1.10	Increasing
	Summer	1.03	0.37	1.35*	0.33	-0.36	1.13	-0.15	0.93	stable
	Monsoon	0.139	0.06	1.32*	0.95	-0.94	2.98	-0.44	2.48	Stable
2005-2070	Annual	0.18	0.03	0.29NS	0.11	-0.83	1.06	-0.59	0.82	Stable
	Winter	0.41	0.60	3.97****	0.45	0.17	0.72	0.26	0.65	Increasing
	Summer	-0.17	0.08	0.81NS	-0.09	-0.41	0.22	-0.33	0.14	Stable
	Monsoon	-0.04	0.02	0.78NS	-0.26	-1.06	0.56	-0.85	0.35	Stable

****- 0.1%, ***-1%, **-5%, *-10% significant level

ET during monsoon season is 132 mm century^{-1} with goodness of fit of 0.74. The Maan-Kendall statistics (Table-7) showed that the decreasing trend was significant at 10% level. The decreasing rate of crop evapotranspiration was due to increase in the soil moisture stress because of decrease in monsoon rainfall. The variation of decadal average of evapotranspiration during monsoon season for the future period 2006-2070. It can be seen that that trend of decadal average of evapotranspiration-ET is not definite. The amount of evapotranspiration during monsoon season was found low because of low rainfall in Aji basin. The Table 4 shows that the decreasing rate of evapotranspiration-ET during monsoon season is 22 mm century^{-1} with goodness of fit of 0.18. The Maan-Kendall statistics (Table-4) shows that the decreasing of evapotranspiration-ET during monsoon season is insignificant. The Sens slope statistics also supported the Maan-Kendall

Table 4: Maan-Kendall and Sens slope statistics for monsoonseasonal ET duringthe past (1970-2005) and future (2006-2070)

Period	Best fit Trend slope	R2	Man-Kendall (Z)	Sens slope	1% level		5% level		ET Trend
					Lower	Upper	Lower	Upper	
	mm year^{-1}			mm year^{-1}	mm year^{-1}	mm year^{-1}	mm year^{-1}	mm year^{-1}	
1970-2005	-1.31	0.74	1.57	-1.44	-3.39	0.90	-3.00	0.35	Stable
2006-2070	-0.21	0.18	0.62	0.27	-0.99	1.55	-0.67	1.16	Stable

****- 0.1%, ***-1%, **-5%, *-10% significant level

statistics. The Sens slope was found negative which was insignificant during monsoon season.

The trend of ET increases for the decade from 1971-80 to 1981-90, 2001-10 to 2011-20, 2021-2030 to 2031-2040 and 2061-70 to 2071-80. The evapotranspiration-ET decreases for the decade from 1981-90 to 2001-10, 2011-20 to 2021-2030 and 2031-40 to 2031-60. In fact, there is no definite trend in the decadal average of evapotranspiration-ET during monsoon season because of indefinite rainfall trend. However, overall, there may be an increase in evapotranspiration in the future if there will not be moisture deficiency. The ET may decrease during monsoon season at -42 mmcentury^{-1} with goodness of fit of 0.56. The decreasing trend of ET during the monsoon season indicated the uneven temporal distribution and insufficient rainfall in the Aji basin. However, Döll and Siebert (2022) reported that under the IPCC SRES A2 and B2 scenarios as interpreted by two climate models, it was projected that the net irrigation requirements of China and India, the countries with the largest irrigated areas worldwide, would change by +2% to +15% in the case of China, and by −6% to +5% in the case of India, by 2020, depending on emissions scenarios and climate model (Döll and Siebert, 2002).

3.4. Groundwater recharge

The Intergovernmental Panel on Climate Change (IPCC) report noted a comparative lack of studies addressing the effects of climate change on groundwater (IPCC, 2007). This challenge has been taken up by the groundwater research community and has resulted in an increasing focus of study in this field in recent years (Green *et al.,* 2011; Taylor, 2013), although there still remains many aspects of the climate change effects on groundwater that have not been well studied. Knowledge of future recharge rates is desirable in order to promote proactive management of groundwater; as historical observations may not be an appropriate basis for management under a future climate. Therefore, considering the above in views, the present effort was made to assess the groundwater recharge in Aji basin and climate change impacts on it. The Mann-Kendall and Sens slope statistics of the times series data of groundwater recharge was carried out separately for the past (1970-2005) and future (2006-2070) and was found as shown in Table 5. The groundwater recharge during monsoon season was found as 42 mm, 21 mm and 20 mm during the period 1970-2005, 2006-2040 and 2041-2070 respectively. The groundwater recharge was found mostly during monsoon season. It could be seen that the groundwater recharge is decreasing from 1970 to 2005 except the decades-1970-80 and 1981-90. In fact, no definite trend in groundwater recharge was found. The insignificant decreasing rate of groundwater recharge during monsoon season is 103 mm century^{-1} with goodness of fit of 0.28. The Maan-Kendall statistics (Table-5) showed that the decreasing trend was not significant. The Sens slope statistics also supported the Maan-Kendall statistics. The Sens slope was found negative which was also not significant.

It can be seen that trend of decadal average of groundwater recharge is not definite. The amount of groundwater recharge during monsoon season was found low because of low rainfall in Aji basin. The table 5 shows that the insignificant decreasing rate of groundwater recharge during monsoon season is 33 mmcentury^{-1} with goodness of fit of 0.30. It seems that there cannot climate change impact on the groundwater recharge. The groundwater resources in the Aji basin will be same as in past. The Maan-Kendall statistics (Table-5) also showed that there will not be climate change impacts on the groundwater resources The Sens slope statistics also supported the Maan-Kendall statistics. The Sens slope was found negative which was insignificant during monsoon season.The trend of ground water recharge increases for the decade from 1971-80 to 1981-90, 2001-10 to 2011-20 and 2031-40 to 2061-70. The groundwater recharge decreases for the decade from 1981-90 to 2001-10 and 2011-20 to 2031-40, In fact, there is no definite trend in the decadal average of groundwater recharge during monsoon season because of indefinite rainfall trend. However, overall, it can be said that there may not climate change impacts on groundwater resources of the Aji basin.

3.5. Probability Distributions

The best fit probability distribution for the past and futuretime

Table 5: Maan-Kendall and Sens slope statisticsfor groundwater recharge for the past (1970-2005) and future (2006-2070) during monsoon season

Period	Best fit Trend slope	Average ground-water recharge	R2	Man-Kendall (Z)	Sens slope	1% level		5% level		Trend
						Lower	Upper	Lower	Upper	
	mm $year^{-1}$	mm $season^{-1}$			mm $year^{-1}$	mm $year^{-1}$	mm $year^{-1}$	mm $year^{-1}$	mm $year^{-1}$	
1970-2005	-1.03	42	0.28	0.45	-0.22	-2.29	1.12	-1.82	0.81	Stable
2006-2070	-0.32	20.5	0.29	0.86	0.04	-0.15	0.34	-0.07	0.25	stable

****- 0.1%, ***-1%, **-5%, *-10% significant level

series of water balance components of monsoon period were assessed. The reference evapotranspiration at different probability predicated using best fit empirical distribution for annual winter, summer, and monsoon season during past and future (Table-6 show that annual ET_o will increase by 1.9% on an average in the future as compared to the past. However, at lower probability (extreme event), it may decrease by -0.4%. The past annual reference evapotranspiration varied from 1897 mm (at 90% probability) to 2214 mm (at 0.01% probability), while it can be 1950.6 mm (at 90% probability) to 2124 mm (at 1% probability), in the future. The mean and median of annual ET_o can be increased by 1.9% and 2.4% in future as compared to past. The highest increase of reference evapotranspiration in the future will be during winter season as compared to other seasons of the year. This may be due to higher warming rate of night during winter. This may increase the crop water requirement and decrease yield of winter crops. The lowest impacts of global warming on crop water requirements will be during summer season in the future. The crop water requirements of summer crops may even decrease by 0.3% on an average in the future as compared to the past period. During monsoon seasons, the crop water requirements may increase by 1.5% in the future as compared to past. The increases in crop water requirement will be higher at higher confidence level. The crop water requirements during winter, summer and monsoon season may increase/decrease by the tune of 6.4%, - 0.3% and 1.5% during winter, summer and monsoon season respectively in the future as compared to the past, due to climate change impacts.

The Frechet type (Fisher – Tippett-2) probability distribution

Table 6: Reference Evapotranspiration during different seasons in thepast and future at different probability

Probability of exceedance	Annual ETo(mm)			Winter ETo(mm)			Summer ETo(mm)			Monsoon ETo(mm)		
	Past	Future	% change	Past	Future	% change	Past	Future	% change	Past	Future	% change
0.9	1896.6	1950.6	2.8	409.2	444.4	8.6	677.7	675.1	-0.4	771.7	774.1	0.3
0.8	1916.3	1969.5	2.8	421.5	451.9	7.2	684.1	683.9	0.0	791.5	799.9	1.1
0.7	1931.7	1988.5	2.9	429.4	457.3	6.5	689.1	689.6	0.1	805.5	816.2	1.3
0.6	1945.6	2007.6	3.2	435.5	462.0	6.1	693.6	694.3	0.1	817.4	829.1	1.4
0.5	1959.3	2007.6	2.5	440.8	466.4	5.8	698.1	698.5	0.1	828.3	840.6	1.5
0.4	1973.7	2026.8	2.7	445.7	470.8	5.6	702.8	702.7	0.0	838.8	851.8	1.6
0.3	1990.0	2046.1	2.8	450.5	475.4	5.5	708.0	707.2	-0.1	849.7	863.7	1.6
0.2	2010.2	2046.1	1.8	455.7	480.8	5.5	714.6	712.6	-0.3	861.8	877.8	1.8
0.1	2040.0	2084.9	2.2	462.2	487.8	5.5	724.3	720.6	-0.5	877.1	898.1	2.4
0.01	2117	2124	0.30	475	502	5.60	749	744	-0.70	904	953	5.50
0.001	2173	2164	-0.40	483	508	5.20	767	764	-0.30	914	1001	9.50
0.0001	2214	2204	-0.50	488	511	4.70	780	784	0.50	918	1045	13.80
Mean	1964	2002	1.90	438	466	6.40	700	698	-0.30	826	838	1.50
Median	1952	1999	2.40	438	464	5.90	698	698	0.00	823	839	1.90

was found best fit for the time series of past and future monsoon rainfall. The MADF, ECF and ECPV performance indices were found as 1.8%, 0.997 and 0.999 for the part rainfall and 2.74%, 0.993 and 0.999 for future rainfall respectively. The past and future monsoon crop evapotranspiration time series followed the Generalized Gumbel type probability distribution with MADF, ECF and ECPV performance indices of 1.8%, 0.996 and 0.999, and 1.53%, 0.998 and 0.999 respectively. The time series of past and future monsoon runoff and future ground water recharge followed the Poisson type, Log-logistic and Generalized logistic probability distribution with MADF, ECE and ECPV as 1.98%, 0.996 and 0.999, 1.8% 0.996 and 0.999, and 2.23%, 0.995 and 0.999 respectively. The Root-normal probability distribution was found best fit to the time series of past monsoon ground water recharge with performance indices of MADF, ECF and ECPV values as 2.25%, 0.995 and 0.999 respectively (Table-7b). It can be seen that the best fit probability distribution for each data series of water balance components as well as reference evapotranspiration has lowest mean absolute differences and highest efficiency coefficient between calculated and observed values (Table 7).

It can be seen in Table 8 that the monsoon seasonal rainfall will be decreased in the future due to climate change impacts. However, the extreme rainfall (100 year return period) event will be increased in the future by the tune of 39%. Similarly, the runoff will be decreased in the future but the extreme event (100 year return period) of runoff will be increased by the tune of 87.5%. The extreme rainfall event will not help to increase evapotranspiration and ground water recharge due to lesser scope of opportunity time for infiltration. The extremity (100 year return period) in the crop evapotranspiration and ground water recharge may be decreased by -5.7% and -5.8%

Table 7: Best fit probability distribution along with its parameters and performance indices for time series of water balance components during monsoon season in the past and future

Variable	Duration	Period	Best fit probability distribution	C D F $P(x \le X)^*$	Parameters value	Fitted Probability distribution Cumulative probability of non-exceedance $P(x \le X)^*$
Rainfall	Monsoon	Past	Frechet type (Fisher-Tippett 2)	Frechet type (Fisher-Tippett 2)	C =-1452 A =-6.64169 B = 49.8890	$=e^{-\left[\frac{\frac{(x-(-1452))}{-49.8890}}{e-6.64169}\right]^{-6.64169}}$
		Future	Frechet type (Fisher-Tippett 2)	P(x≤X) = 1-exp{-(A*X^E+B)}	C = -53 A =-1.88227 B =10.5627	$=e^{-\left[\frac{\frac{(x-(-53))}{-10.5627}}{e-1.88227}\right]^{-1.88227}}$
Runoff	Monsoon	Past	A-symptotic exponential (Poisson-type)	P(x≤X) = 1-exp{-(A*X^E+B)}	E= 8.50E-001 A= 8.7753E-003 B= 0.0180717	$=1-e^{-((8.7753E-003)x^{(8.50E-001)}+0.0180717)}$
		Future	Log-logistic	P(x≤X) = 1/{1+exp(A*LnX+B)}	A = -1.20156 B = 5.00776	$=\frac{1}{1+e^{(-1.20156\ \ln(x)+5.00776)}}$
Crop Evapot-Transpiration	Monsoon	Past	Generalized Gumbel type	P(x≤X) = exp[-exp{-(A*X^E+B)}]	E=2.55E+000 A =2.9180E-006 B= -1.34235	$=e^{-e^{-((2.9180E-006)x^{(2.55E+000)}+(-1.34235))}}$
		Future	Generalized Gumbel type	P(x≤X) = exp[-exp{-(A*X^E+B)}]	E=1.89E+000 A= 1.4528E-004 B =-1.56168	$=e^{-e^{-((1.4528E-004))x^{(1.89+000)}+(-1.56168))}}$
Ground-water recharge	Monsoon	Pas	Root-normal	-	-	-
		Future	Generalized logistic	P(x≤X) = 1/{1+exp(A*X^E+B)}	E=3.20E-001 A =-1.39856 B=2.92444	$=\frac{1}{1+e^{(-1.39856x^{(3.20E-001)}+2.92444)}}$

Table 7: Continue...

Table 7: Continue...

Variable	Duration	Period	Best fit probability distribution	MADF** (%)	Performance Indices	
					ECF***	ECPV****
Rainfall	Monsoon	Past	Frechet type (Fisher-Tippett 2)	1.80	0.997	0.999
		Future	Frechet type (Fisher-Tippett 2)	2.74	0.993	0.999
Runoff	Monsoon	Past	A-symptotic exponential (Poisson-type)	1.98	0.996	0.999
		Future	Log-logistic	2.09	0.997	0.999
Crop Evapot Transpiration	Monsoon	Past	Generalized Gumbel type	1.80	0.996	0.999
		Future	Generalized Gumbel type	1.53	0.998	0.999
Groundwater recharge	Monsoon	Pas	Root-normal	2.25	0.995	0.999
		Future	Generalized logistic	2.23	0.995	0.999

* CDF=Cumulative probability distribution function; P(x≤X) =Probability of variable-x being less than given X-value; **MADF= Average of absolute differences between calculated and observed frequencies (%); *** ECF=Efficiency coefficient(R) of calculated and observedcumulative frequency; ****ECPV=Efficiency coefficient (R) of calculated and observed variable values

Table 8: Water balance components during past and future at different probability

Probability of exceedance	Monsoon Rainfall (mm)			Monsoon runoff (mm)			Monsoon evapotranspiration (mm)			Monsoon groundwater recharge (mm)		
	Past	Future	% change	Past	Future	% change	Past	Future	% change	Past	Future	% change
0.9	161	123	-23.9	15	10	-30.4	114	91	-20.2	1.0	0.1	-87.1
0.8	251	160	-36.3	41	20	-50	140	112	-20	6.6	1.4	-79.5
0.7	327	195	-40.3	74	32	-56.6	157	127	-19	14	3	-75.3
0.6	402	234	-41.8	114	46	-59.7	170	140	-17.9	23	6	-72
0.5	481	280	-41.9	166	65	-61	183	152	-16.9	32	10	-68.9
0.4	572	338	-40.9	232	91	-60.9	195	164	-15.8	44	15	-65.5
0.3	684	420	-38.6	321	131	-59.3	208	178	-14.5	58	22	-61.7
0.2	841	554	-34.1	454	205	-54.9	223	194	-13.1	77	34	-56.3
0.1	1115	852	-23.6	695	402	-42.1	245	218	-10.9	108	58	-46.6
0.01	2204	3060	38.8	1578	2957	87.5	298	281	-5.7	204	192	-5.8
0.001	3723	10683	187	2546	20249	695.4	339	332	-1.9	292	443	51.8
0.0001	5867	36439	521	3574	137717	3754	373	377	1.1	377	886	135
Mean	562	417	-25.8	262	186	-29	180	153	-15	43	21	-51.2
Median	466	268	-42.5	152	59	-61.2	183	148	-19.1	35	9	-74.3

respectively. On an average, the water balance components like rain fall, runoff, crop evapotranspiration and ground water recharge may be decreased by -26%, -29%, -15% and -51% in the future as compared to part due to climate change impacts.

4. Conclusion

The day maximum temperature may increase by 3.31°C, 1.46°C and 2.52 °C up to end of 2070 over the present 34.51°C, 38.65°C, 36.01°C and minimum temperature by 3.35°C, 5.80°C and 3.07 °C up to end of 2070 over the present 14.83°C, 26.38°C and 22.37°C in winter, summer and monsoon season respectively. Therefore, the adoptions of heat resistant crop varietieswith frequent irrigations of smaller depth through MIS particularly during summer season should be promoted to lessen the adverse effects of higher temperature. The crop water requirements during winter, summer and monsoon season may increase/decrease by the tune of 6.4%, - 0.3% and 1.5% during winter, summer and monsoon season respectively in the future as compared to the past, due to global warming. On an average, the water balance components like rain fall, runoff, and ground water recharge may be decreased by -26%, -29%, and -51% in the future as compared to past. The monsoon seasonal rainfall and runoff will be decreased in the future but the extreme event (100 years return period) will be increasedby tuneof 39% and 87.5% respectively due to climate change impacts.

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