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Impact of Climate Change on Krishna Western Delta Using Swat Hydrological Model

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ABSTRACT

Quantitative analysis of expected changes in water availability and crop yields under changing climate scenarios has been carried-out in Krishna Western Delta. The area located geographically between 16.45Ú-15.56 ÚN latitude and 79.85Ú- 80.83 ÚE longitude and has a command area of 5275.21 km^2. The Soil and Water Assessment Tool (SWAT) model is applied for the resources in the study area and calibrated. The water balance studies in KWD indicated that 59.43 % of total water resources goes as water yield, 38.13 % as evapotranspiration, 2.3 % as change in aquifer storage and 0.14 % as soil moisture storage change.In the model study, the hydrological responses to variations of temperature (0 ÚC, +1 ÚC and +2 ÚC), and precipitation (0%, -10 %, and -20 %) have been considered based on Intergovernmental Panel on Climate Change (IPCC) projections. It is observed that the water availability in the system reduces in all changing climate scenarios. Both water yield and soil moisture storage decreases by 19 % in decrease of 20 % rainfall and increase of 2 ÚC temperature scenario. Average agriculture productivity in the study area decreases from 723 to 637 t ha^{-1} in different climate scenarios. From the simulation results, rice will be the most affected crop in the changing climate conditions. Rice crop yield decreases by 39 % followed by grams 19 %, sunflower 10 %, maize 7 % and cotton 4 %.

Key words : Climate change impact, Krishna Western Delta, SWAT (Soil and Water assessment Tool).

Climate change and disasters are fast emerging as the most defining challenges of the 21st century. The temperatures in 2100 are expected to be between 1.1 - 6.4 ÚC higher than temperatures in 1900, accompanied by changes in rainfall intensity and amount (IPCC, 2007). Based on the measurements of the Indian Meteorological Department (IMD) has shown that the all India mean annual temperature has increased by 0.5 °C in the period 1901 – 2003. Currently, Global Circulation Models (GCMs) are the most powerful climate models to predict changes in hydro-meteorological variables due to increasing levels of atmospheric greenhouse gases (IPCC, 2001). Hydrologic models are often combined with climate scenarios generated by climate models to produce effects of climate change on water resources. The Soil and Water Assessment Tool (SWAT) (Arnold *et al.,* 1998) was used for this study is to determine quantitatively the expected changes of water availability and crop yield in the Krishna Western Delta under changing climate scenarios. This gives an opportunity to define the degree of vulnerability of water resources in the study area.

MATERIAL AND METHODS

2.1. Description of study area

An area of 5275.21 km^2 was selected in Krishna western delta (KWD) and its surrounding area covers parts of Guntur and Prakasam districts in Andhra Pradesh. The study area is bounded by latitude 16.45Ú-15.56 ÚN and longitude 79.85 - 80.83 ÚE and has 85 km coast along Bay of Bengal. The study area experiences the sub humid climate, characterized by heavy rains during August to September. The mean annual maximum and minimum temperature in the area is 34.5 ÚC and 23.9 ÚC respectively, average annual rainfall was 1480 mm with relative humidity of 0.679 (for last 30 years average,1980-2010). KWD is characterized by flat lands have deep to very deep imperfectly drained calcareous cracking clay soils with frequent flooding and water logging. KWD is an agriculture intensive area with net area sown is about 71.45 % of the total geographical area and has a cropping intensity of 165 %. Rice based cropping systems are predominant in KWD and rice is grown during kharif season, while blackgram, maize, chickpea maize are grown in rabi season.

2.2. Data collection and analysis

Spatial data used in the study included a digital elevation model (DEM), land use, soil data, and climatic data. A digital elevation model with a resolution of 90 m was downloaded from SRTM (Shuttle Radar Topographical Mission). Land use data downloaded from FAO (Food and Agriculture Organization) which has a resolution 1 km. Soil data used in the study with resolution 56 m was from NRSC (National Remote Sensing Centre). Daily stream records at Returu, which is one of the gauging station were obtained from the Department of Hydrology, Hyderabad. The gridded weather data such as daily maximum and minimum air temperature, precipitation, relative humidity and wind speed for the years 1979 to 2010 were obtained from Indian Meteorological Department (IMD). The canal water release to KWD data was collected from the Superintendent Engineer, I & CAD, Tenali. Agriculture management practices in the study area collected from Directorate of Economics & Statistics, Hyderabad (Agriculture Statistics at a Glance 2010-2011).

2.3 Soil and Water Assessment Tool (SWAT) model

The model employed in this study is "Soil and Water Assessment Tool"(SWAT2009) developed by Dr. Jeff Arnold for the USDA Agriculture Research Service. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT includes approaches, describing how precipitation, temperature, and humidity affect ET, soil moisture content, runoff generation, and has been used as a tool to investigate climate change effects.

2.4. Model setup

SWAT model divide the study area into 72 sub-watersheds, based on the elevation values and further divided into 251 hydrologic response units (HRUs) based on soil, land use data. Surface runoff was estimated by the SCS Curve Number method from daily precipitation records using default values

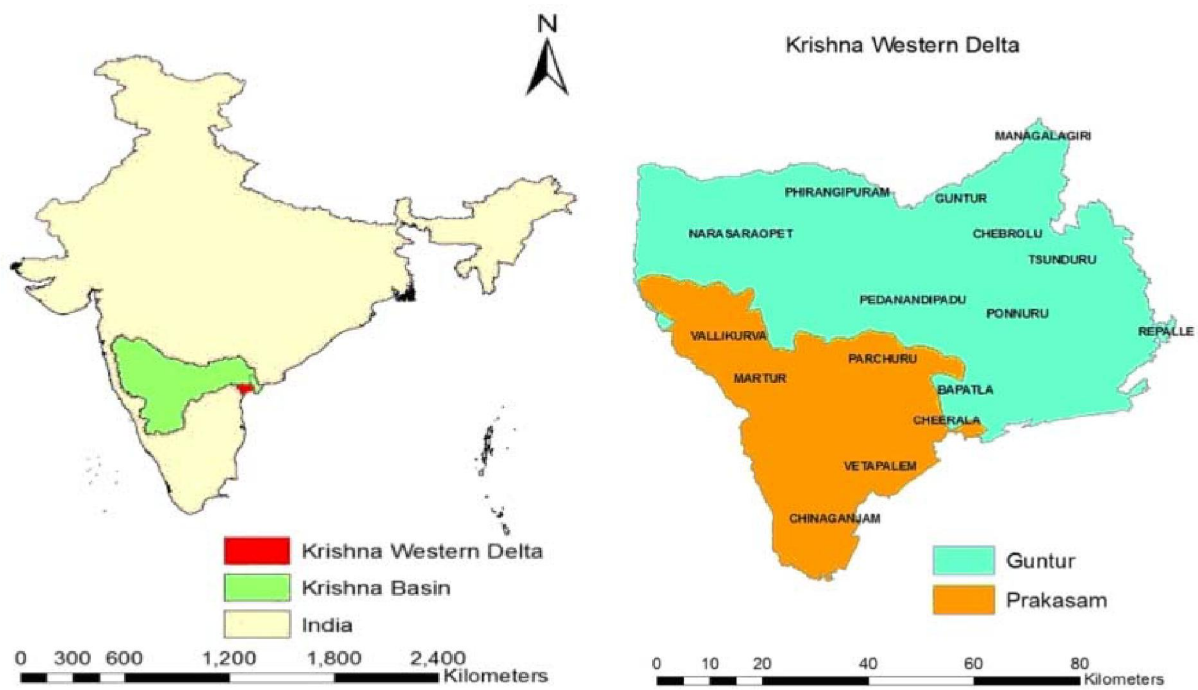


Fig.2.1 Location of Krishna western Delta

provided in SWAT, which were acceptable based on landuse and soil data in the study area. Crop yield and biomass production is also calculated along with the water balance components in the study area.

2.5. Model calibration

Model calibration was conducted by comparing the SWAT simulated data with the observed discharge at Returu station on daily basis. The calibration was conducted for a period of 5 year from 2005 - 2009 daily average flow. Two statistical criteria were used to evaluate the modelling results: coefficient of determination (r^2) and Nash-Sutcliffe Efficiency (E).

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}\sqrt{n(\sum y^2) - (\sum y)^2}}$$

Where n is no. of pairs of data, x is observed value, y is the simulated value.

$$E = 1 - \frac{\sum_{t=1}^{T} (Q_o^t - Q_m^t)^2}{\sum_{t=1}^{T} \left(Q_o^t - \overline{Q_o}\right)^2}$$

Where Q_o is observed discharge, and Q_m is modeled discharge, Q_o^t is observed discharge at time t, $\overline{Q_o}$ is the mean of observed discharge.

2.6. Scenarios of precipitation and temperature changes

The precipitation and temperature change is the main aspects of climate changes into consideration.According to the study in Krishna basin (Gosain et al.,2006)a reduction of precipitation by 20% of the current value has been predicted (using HadRM2 generated weather data) in the sub-basins of Krishna by 2060 has showed. Precipitation change scenarios in this study consist of three situations such as decreases by 20 %, 10 %, and unchanged. Based on the General Circulation Model (GCM) for Indian sub-continent, IPCC project a warming of 2 - 4.7 °C, by the year 2100 (A1B scenario). Temperature change scenarios for the years 2030-2060 consist of three situations such as increases by 1 ÚC, 2 ÚC, and unchanged.

RESULTS AND DISCUSSION

3.1. Runoff response

Average daily flow at Returu gauging station for the period 2005 to 2009 was used for calibration of the model (Figure. 3.1). The coefficient of determination (r^2) between average daily measured and simulated flow reaches 0.59 and Nash-Sutcliffe Efficiency (E) 0.45. From these statistical measures, it is indicated that the simulated flow is close to the measured flow.

3.2. Present Water Budget in Krishna Western Delta

The model predicted monthly water balance components for the year 2010 are shown in the Fig.3.2. Precipitation and canal water are the water inputs to the system. The water yield indicated the total amount of water flowing out of the area as surface runoff, lateral flow and ground water flow. From this figure, it is indicating that water yield is decreased from January to June and July onwards it is increased up to November.

The share of each hydrological component in the annual water balance of the study area indicated that 59.43 % of the inputs (precipitation, canal water, initial water storage) will contributes the water yield. The second most contributing component is evapotranspiration (38.13 %), then the change in aquifer storage (2.3 %) and the change in the soil moisture storage (0.14 %).

The distribution of water balance components greatly depend upon the land use/land cover condition of the area and different land use classes are compared such as forest, single crop (black gram in rabi season), fallow/waste land and bermuda grass (urban area), which all are in the same type of soil and in a same slope class (0 – 999 m). The distributions of hydrologic components in different land use conditions are represented in Table 3.1. Maximum evapotranspiration will be in forest condition as 55 %, maximum surface flow observed in bermuda grass (37 %), maximum ground water flow (lateral flow is also included) obtained in fallow/waste land (31 %) and soil water storage (sum of soil moisture storage and aquifer storage) is almost same for all the land use conditions.

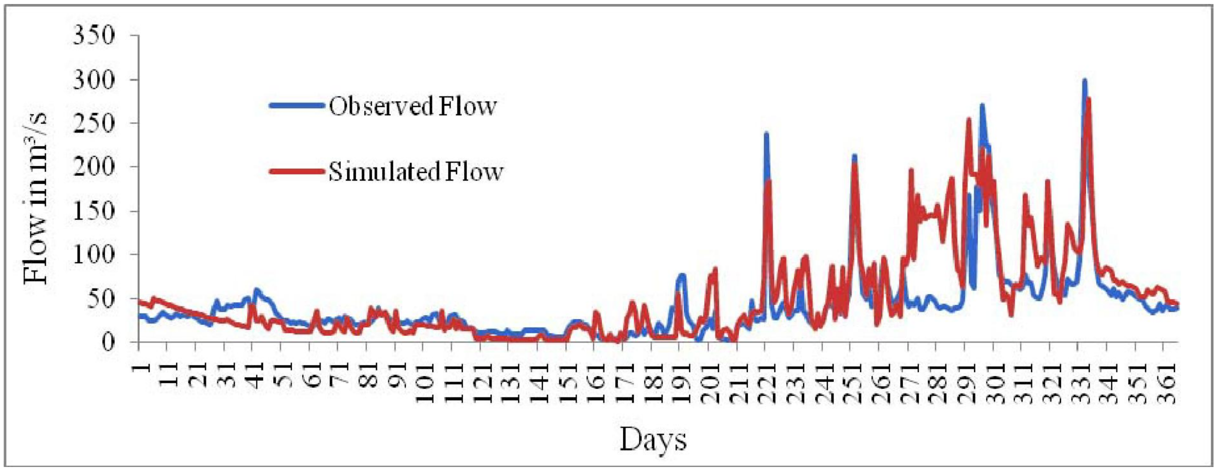


Fig. 3.1 Comparison of observed and simulated average daily stream flow at Returu gauging station for the period 2005 - 2009.

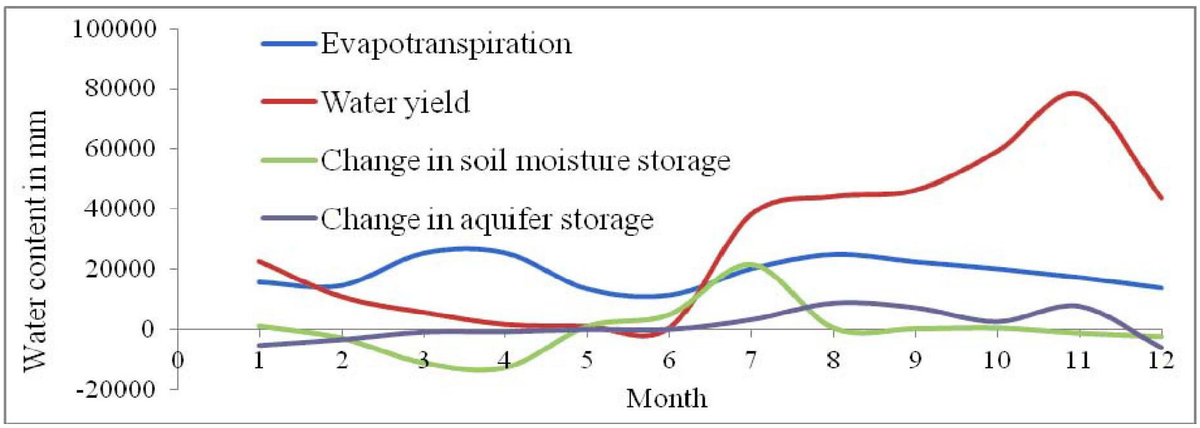


Fig.3.2 Monthly variation of hydrological components in Krishna Western Delta in 2010.

Table 3.1. Hydrologic factors of different land use classes in Krishna Western Delta (in per cent).

Land use	Evapotranspiration	Surface flow	Ground water flow	Soil water storage
Forest	55	17	25	3
Single crop	41	32	24	3
Bermuda grass/ urban area	43	37	18	2
Fallow/waste land	38	28	31	3

Table 3.2. Hydrologic factors of different soils in Krishna Western Delta (in Per cent).

	Evapotranspiration	Surface flow	Groundwater flow	Soil water storage
Clay	16.40	30.20	50.30	3.10
Clay loam	11.65	62.54	24.54	1.27
Loam	24.65	25.30	38.92	11.13
Sandy loam	12.63	28.79	54.75	3.83

In the study area mainly there are four kinds of soil, such as sandy loam, loam, clay and clay loam. In same land use condition (rice – kharif, blackgram – rabi), and in same slope class (0 - 999 m) water budgeting in four different soils are compared in Table 3.2. In clay loam soil, surface flow (62.54 %) is the main component in the water balance, whereas in all other soils ground water flow is the major component. Maximum ground water flow is observed in sandy loam soil as 54.75 %, and minimum in clay loam soil as 24.54 %. Maximum soil moisture storage is obtained in loam soil as 11.13 % and minimum in clay loam soil as 1.27 % in the study area.

3.3 Water balance in future climate scenario

Being the very sensitive parameter, climate change adversely affects the hydrologic cycle in the study area. There are nine climate scenarios including the present condition. Table 3.3 shows the annual water budgeting.

Evapotranspiration is gradually increasing as the temperature is increasing and it is gradually decreasing as the precipitation decreases. As the temperature increases water yield decreases in order to compensate with the evapotranspiration and it is decreasing as the precipitation amount decreases. Soil water storage component is reducing as the temperature increase and also as the precipitation decreases.

The average values of hydrological components in the study area are presented in Table 3.3. Distribution of water balance component at each point in the study area is different. The present spatial distribution and percentage change of water yield and soil moisture storage in climate scenarios are represented in Fig.3.3 and Fig.3.4 respectively. Average sub-basin values are presented in these figures.

Present (2010) spatial distribution is shown in each hydrological component followed by the percentage change in all climate scenarios in Krishna Western Delta. Annual evapotranspiration ranges between 200 to 1600 mm in the study area. The percentage change of evapotranspiration ranges from -10 to 3 % in climate scenarios. Annual water yield generated from the study area ranges 1,300 to 17,000 mm and the percentage change ranges from -30 to 5% in climate scenarios. Annual soil water storage in the study area ranges from 10 to100 mm and the percentage change ranges from -35 to 15 % in climate scenarios.

3.4 Agriculture productivity

The crop productivity obtained in different climatic scenarios is presented in Table 3.4. In all the cases, it is low compared to the present condition. Minimum productivity is obtained in 20 %, 2 ÚC scenario as 637 t ha^{-1}.

3.5 Crop yield in climate scenarios

The yield of different crops in climate scenarios is shown in Table 3.5. In maize crop the yield decreases from 5.18 to 4.82 t ha^{-1} (7 % decrease) whereas in rice crop it is from 2.53 to 1.55 t ha^{-1} (39 % decrease). The yield decrease of tobacco is from 1.75 to 1.65 t ha^{-1}, (6 % decrease), grams is from 1.22 to 0.99 t ha^{-1} (19 % decrease), sunflower is from 1.01 to 0.91 t ha^{-1} (10 % decrease) and cotton is from 0.75 to 0.72 t ha^{-1} (4 % decrease). In each crop, effect of temperature increase and rainfall decrease is different. For example in rice crop, the temperature increase has more effect than the precipitation decrease in the yield reduction and an opposite trend can be observed in the maize crop.

4. Conclusion

Based on DEM, land use information and soil data in Krishna Western Delta, the applicability of the SWAT model in this basin is investigated by using the observation data obtained from 2005 to 2009 to calibrate the parameters of the model, and the hydrological response to climate change was analyzed. It concludes as follows: (1) SWAT proved to be a useful tool for assessing the effects of climate variability in Krishna Western Delta; (2) According to watershed practical condition, 9 sets of different temperature and precipitation combinations was established to simulate hydrological parameters under different scenarios. Simulation results show that when precipitation keeps invariable, temperature increase would increase average annual evaporation and potential evaporation, and decrease water yield. When temperature keeps invariable, precipitation increase would increase evaporation and water yield. The agriculture productivity decreases with the change

Table 3.3. Comparison of annual water budgeting in climate change scenarios (rainfall and temperature changes).

Tempe-rature increase	Evapotranspiration			Water yield (surface flow + ground water flow)			Soil water storage (soil moisture storage+ aquifer storage)		
	Rainfall reduction			Rainfall reduction			Rainfall reduction		
	0 %	10 %	20 %	0 %	10 %	20 %	0 %	10 %	20 %
0 ÚC	226637	223235	220210	353307	309336	286590	14505	13521	11913
1 ÚC	227207	223867	220911	352698	308686	285880	14506	12818	11903
2 ÚC	228601	225255	222299	351410	307406	284608	14406	12719	11806

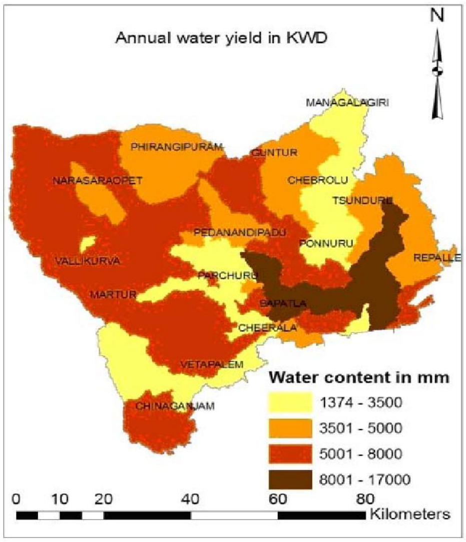
Table 3.4. Comparison of agriculture productivity in climatic scenarios (t ha^{-1}).

Precipitation change	Productivity		
	Temperature change		
	0^oC	1^oC	2^oC
0%	723	693	658
10%	716	687	653
20%	700	670	637

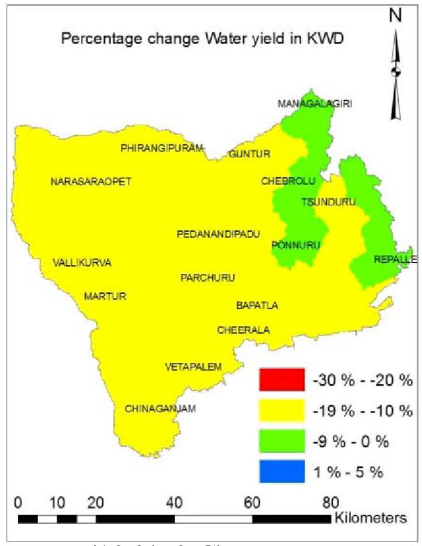
Table. 3.6 Comparison of crop yield in climatic scenarios (t ha^{-1}).

Crop	Rainfall decrease	Temperature increase		
		0^oC	1^oC	2^oC
Maize	0%	5.18	5.17	5.12
	10%	5.11	5.09	5.05
	20%	4.91	4.88	4.82
Rice	0%	2.53	2.02	1.55
	10%	2.52	2.02	1.55
	20%	2.52	2.02	1.55
Tobacco	0%	1.75	1.71	1.65
	10%	1.73	1.70	1.65
	20%	1.73	1.70	1.65
Grams	0%	1.22	1.12	1.05
	10%	1.20	1.11	1.04
	20%	1.12	1.05	0.99
Sunflower	0%	1.01	0.98	0.92
	10%	0.99	0.96	0.92
	20%	0.92	0.92	0.91
Cotton	0%	0.75	0.75	0.73
	10%	0.74	0.74	0.73
	20%	0.74	0.73	0.72

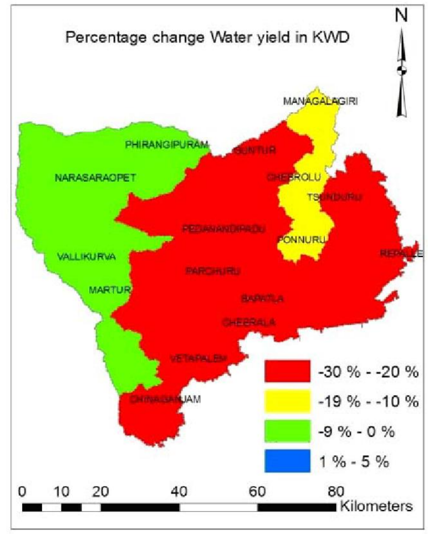
Fig.3.3. Comparison of spatial change in water yield in Krishna Western Delta for a year in different climate.



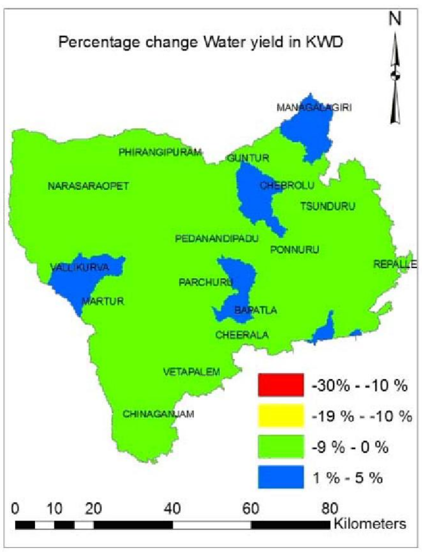
(0 %, 0 °C /Present)



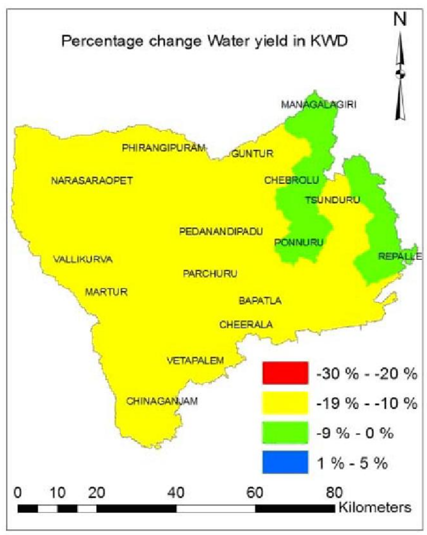
(10 %, 0°C)



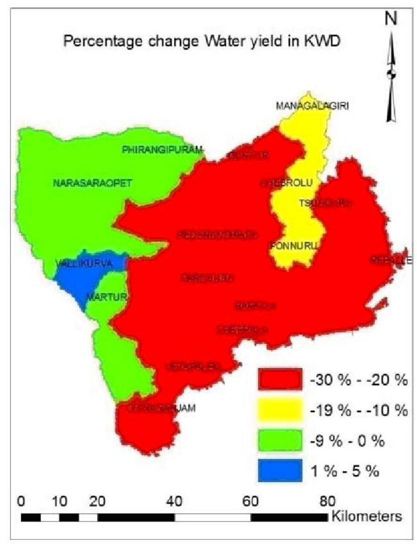
(20 %, 0°C)



(0 %, 1 °C)



(10 %, 1°C)



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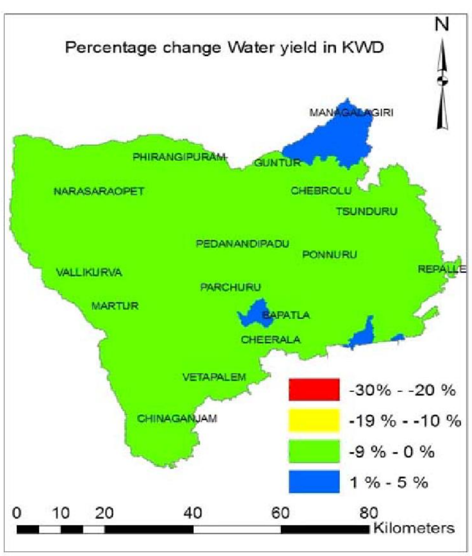

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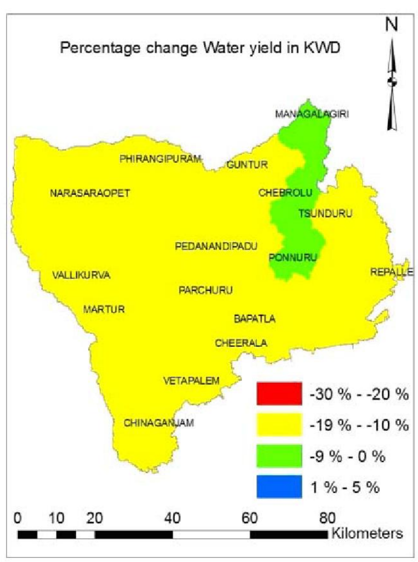
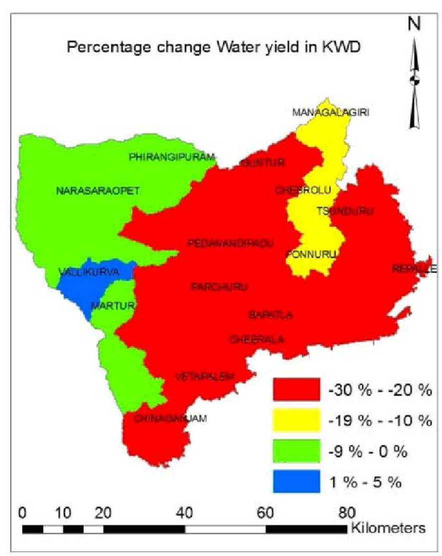
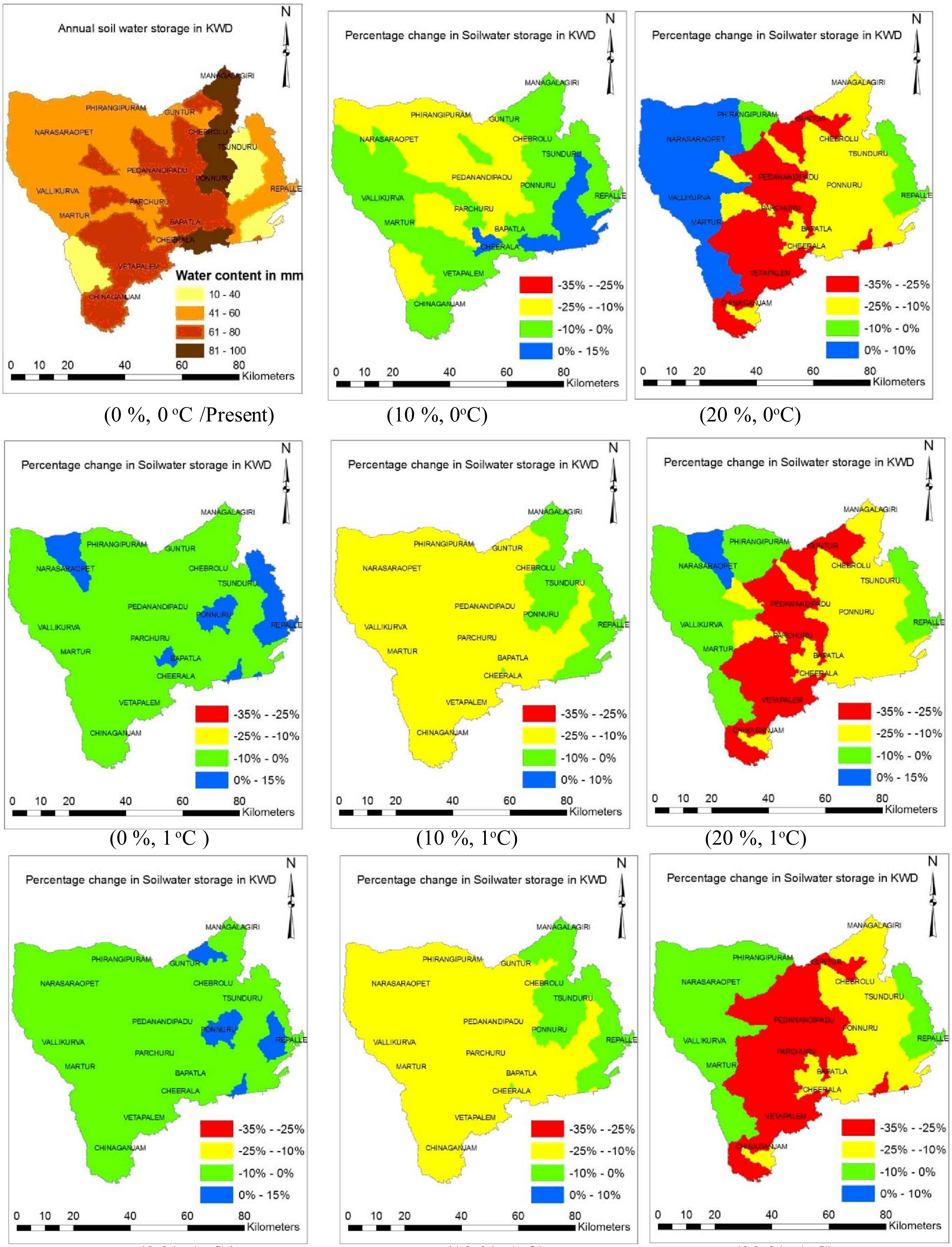


(10 %, 1°C)



(20 %, 1°C)

Fig.3.4. Comparison of spatial change in soil water storage in Krishna Western Delta for a year in different climate scenarios.



(0 %, 0 °C /Present) (10 %, 0°C) (20 %, 0°C)

(0 %, 1 °C) (10 %, 1°C) (20 %, 1°C)

(0 %, 1 °C) (10 %, 1°C) (20 %, 1°C)

in temperature and precipitation. Yield change in the climate scenarios is different for each crop. Simulation results show that rice has maximum yield reduction in the changed climate situation (39 % decrease) followed by grams (19 % decrease).

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