Evaluation of Impact of Climate Changes on the Lower Seyhan Irrigation Project, Turkey

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1. Introduction

Agriculture strongly depends on water resources and climate conditions, and global warming will have increasing impacts on agriculture. This study hopes to quantitatively assess how global warming will affect irrigated agriculture in the 2070s by factoring projected future climate data into computational simulations of crop growth and hydrological structure in the Lower Seyhan Irrigation Project, Turkey. Simulations in this study are not seeking to predict the actual situation for the irrigated area, but are aimed at providing important information that should be considered regarding vulnerabilities in present irrigation management and determining how irrigated agriculture could adapt to a changing climate.

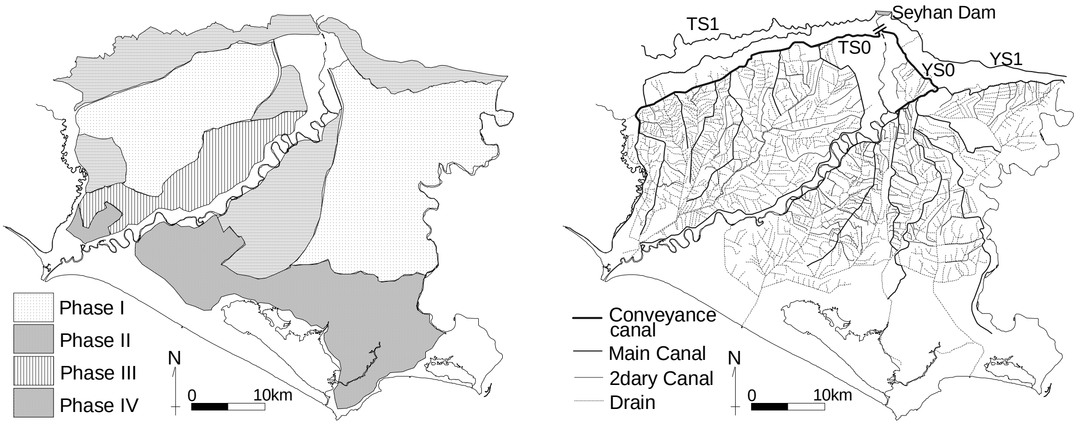
2. Study area

The Lower Seyhan Irrigation Project (LSIP) (Fig.1a) is located on the eastern Mediterranean coast of Turkey. Its construction began in 1960s. The project area of 175,000 ha was divided into four areas and construction for each area was conducted in each project phase. Project phases I – III (133,000 ha) were completed by 1985. The area phase IV that remains incomplete is located in the lowest part of the project area. Although it has no water allocation, irrigated agriculture is also practiced with surplus water from main canals of the completed areas.

Average annual precipitation from 1994 to 2003 in this area was 744 mm (observed at Adana), with most of the precipitation falling during the winter months. According to the projection results by major General Circulation Models (GCMs), precipitation and river runoff in the Mediterranean Region including the Seyhan River Basin will decrease under warmer climates in the future. In response to the Mediterranean climate, farmers on the upstream side of the basin have been cultivating rain-fed winter wheat; however, in the command area of the LSIP, agricultural production is active mainly during the dry season from spring to autumn and uses a water supply from the Seyhan Reservoir, which stores runoff due to winter precipitation from upstream. As of 2005, winter wheat is cultivated in only 20% of the project area. Although cotton was a dominant summer crop in the LSIP before the 1980s, maize had replaced it by 2000 because of pest and disease problems and economic reasons. Cultivation of citrus has also been increasing gradually since the 1980s. In 2004, the cultivation areas of maize, cotton, citrus, vegetables, and watermelon comprised 45, 9, 13, 4, and 6% of the total area, respectively.

The irrigation canal system of the LSIP consists of two conveyance canals, main canals, secondary canals, and tertiary canals. The two conveyance canals (YS0 and TS0) are diverted at the Seyhan Regulator. All of the main canals branch off these two conveyance canals except for YS1 and TS1, which are diverted directly from the Seyhan Reservoir (Fig.1b). Annual amount of water diversion for the LSIP in 2000 is about $1.6\times10^9 m^3$. It is trending upward since 1990s because of a change of cropping pattern.

Groundwater level exists only 1 – 2 meters bellow the ground surface in most part of the LSIP. Some areas of the LSIP has severe problems of ill-drainage and salt accumulation induced by shallow water table (Cetin et al., 2003) although Turkish government have been carrying out intensive construction of drainage systems in the LSIP since 1960s (Sener, 1986). Several researches on salinity and water logging have been being conducted in the LSIP.



(a) Construction phase

(b) Irrigation and drainage systems

Fig. 1. Lower Seyhan Irrigation Project

3. Methods and materials

Climate data for 2070s derived from projection by climate models and assumed water and crop management in the area was fed to a numerical model that simulates hydrology and crop growth in irrigated agricultural areas. Impacts of climate changes were assessed through evaluation of results of the simulation.

The following two types of impact assessments were carried out in this strudy.

A) Impacts of climate changes on the current water and crop management

This was conducted for assessment of valunerability of the current water and crop management to climate changes as well as for evaluation of sensitivity of the irrigation and agricultural system of the LSIP to climate changes. All data and parameters except for climate data were set to the current situation.

B) Impacts of climate changes and assumed management

Agriculture in the Seyhan River basin may be obliged to change by climate changes. Decrease of precipitation may promote irrigation agriculture in the upper basin where rain-fed agriculture is conducted currently. The LSIP may also change crop and irrigation management to adapt to situations with less water availability. This assessment was conducted to assess impacts of climate changes and such assumed management changes on hydrological environment of the LSIP.

Datasets about water and crop management in the future were created according to the following three assumed basin change scenarios. Soil physics, geology and terrain were fixed.

3.1 Basin change scenarios

In processes to create the basin change scenarios, course of adaptation of the basin and the LSIP against climate changes was considered.

Adaptation scenario 1 (Ad.1)

It is assumed that the LSIP will adapt to climate changes without significant investment for water management. Management water requirement will increase because of deterioration of facilities as well as irrigation water demand at each field-lot will increase because of dryer climate. The LSIP will increase water withdrawal from the river to compensate the increased water requirement.

Incomplete project area (Phase IV) that is irrigated with surplus water from the completed area will be abandoned in this scenario.

Adaptation scenario 2 (Ad.2)

Although available water for the LSIP will decrease because of an irrigation development in the upstream in addition to decrease of run off, increase of irrigated area (completion of Phase IV) will be attained. Increase of management water requirement will be avoided through maintenance of irrigation facilities restricts.

Adaptaion scenario 3 (Ad.3)

While all farms depend on surface water in the scenarios 1 and 2, $0.17\times10^9 m^3$ (about 150mm for the irrigated area) of total water demand in the area is covered by well water in the scenario 3. In this study, it was assumed that well water is applied for 21,900 ha of orchards (citrus and other fruit-tree crops); 780mm in depth annually as much as the surface water irrigation.

3.2 Indices for the assessment

Ratio of actual transpiration (T_a) to potential transpiration (T_p) was used as an index for water stress and relative crop yield. In addition, changes in groundwater level was watched since water logging is one of the most important concern for the LSIP as mentioned above.

3.3 Model for the assessment

A grid-based distributed hydrological model IMPAM (Irrigation Management Performance Assessment Model) (Fig.2) was used in this study. IMPAM was developed by the authors for simulation of hydrology in irrigated agricultural areas. Its spatial scope is from command area of a tertiary canal up to command area of irrigation project. It calculates amount of irrigation water withdrawal to a subject area, precipitation, seepage from irrigation canals, drainage, evaporation from soil surface, transpiration from crops, etc that are major water balance components in irrigated agricultural areas. Soil moisture dynamics in saturated and unsaturated zones are calculated separately by 2-dimensional horizontal model and 1-dimensional vertical model respectively. Crop, irrigation, drainage, water delivery, well water withdrawal modules etc. are assembled on the quasi-three dimensional soil water dynamics model that consists of the 1-dimensional vertical and 2-dimensional horizontal models. All major factors and components in hydrological processes such as crop calendar and its spatial distribution, irrigation and drainage facility arrangement, topography, etc. are included within the spatial scope of the model. Major inputs of IMPAM are indicated in Figure 3. Hydrological processes that have to be described by this model are seepage from irrigation canals, groundwater flow to drainages, interaction between ground surface and groundwater (capillary rising and infiltration), soil surface evaporation, transpiration (soil moisture withdrawal by roots), and groundwater flow. Meteorology, irrigation schedule, landuse-crop spatial distribution, and the irrigation-drainage channels' spatial distribution database are the main input items of this module.

Resolution of horizontal grid can be set freely from ten meters up to about 1 km according to purpose of simulations.

Soil water dynamics

Horizontal water movement in saturated zone (temporal and spatial variation of groundwater levels) is expressed by the advection-dispersion equation (ADE) (Eq.1)

$$\frac{\partial h}{\partial t}=\frac{T}{S}\left(\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}\right)+q_{ssh} \qquad (1)$$

where, h: head, T: transmissivity, S: coefficient of storage, qssh: sink/source flux for the horizontal model.

The sink/source term is calculated for each horizontal node by Eq.2.

$$q_{ssh}=q_{bot}+q_{drain}-q_{seepage}-q_{apl}+q_{well} \qquad (2)$$

where, q_{bot}: bottom flux of 1-dimensional vertical soil-water dynamics model (upward positive), q_{drain}: drainage, $q_{seepage}$: seepage from canal segments, q_{apl}: application loss at each farm-lot, q_{well}: well withdrawal.

Methodologies of calculations of vertical 1-dimensional water movement including matrix potential flux and root water extraction from soil are based on a theory used in SWAP (Soil Water Atmosphere Plant) model (Van Dan et al., 1997) although some parts are simplified. Soil water movement is calculated with the partial differential equation of Richards (Eq.3) for each horizontal node.

$$\frac{\partial \theta}{\partial t}=\frac{\partial\left[K(h)(\partial h/\partial z)+1\right]}{\partial z}-q_{ssv} \qquad (3)$$

where, θ: volumetric coefficient of water content. $K(h)$: soil water conductivity [cm d^{-1}]given as a function of pressure head, q_{ssv}: sink/source term for the 1-dimensional model, that consists of root extraction and preferential flow.

Evaporation and transpiration

Transpiration and evaporation are calculated by two steps. Firstly transpiration without water stress, which is defined as “potential transpiration (T_p)”, and potential evaporation are calculated by Penman-Monteith equation with climate data, minimum canopy resistance, leaf area index (LAI), and crop height. Then they are reduced by functions of soil moisture.

Soil surface evaporation is limited by unsaturated soil moisture conductivity.

Transpiration is given as sum of root water extraction S_a at each depth z (Eq.4):

$$T_a = \int_{-D_{root}}^{0} S_a(z) \qquad (4)$$

where D_{root} is root depth. The S_a is the product of potential root water extraction S_p and a coefficient α that is a function of Feddes et al. (1978) (Eq.5, Fig.3).

$$S_a(z) = \alpha(z) \times S_p(z) \qquad (5)$$

Although potential root water extraction at each depth should be determined by potential transpiration (total root water extraction) and ratio of root length density at each deoth to the total density, variation of the density with depth is oftern ignored (Van Dan, et al., 1997). IMPAM simply calculates the S_p assuming uniform density distribution (Eq.6).

$$S_p(z) = \frac{T_p}{D_{root}} \qquad (6)$$

Cop growth

LAI, root depth and crop height that are used in the calculation of evaporation amd transpiration are calculated as a function of accumulated temperature for each farm plot.

Irrigation and seepage from canals

Irrigation schedule for each plot is given by table (day-plot-depth) or is calculated by the irrigation module that functions to keep soil water content not less than a threshold.

Losses in conveyance and delivery often occupy large parts of water balance in irrigated agricultural areas. IMPAM calculates spatial and temporal distribution of conveyance and delivery losses conceptually according to a time schedule of water delivery. Evaporation is ignored, and conveyance losses only consist of seepage loss in the model. The water delivery schedule is given as a table (canal segment-day) or is created by Water Distribution Module of the model.

Drainage

Drainage contains tree types of water: water directly discharged from irrigation canals (tail water), quick drainage of infiltration from the soil surface through cracks, and oozing from saturated zone. The oozing is calculated as a function of groundwater level, density and level of drain bottom.

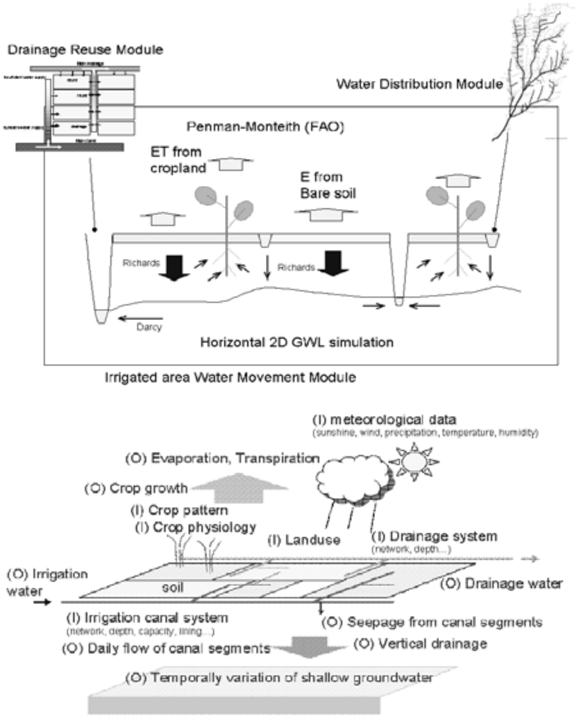


Fig.2. Concept and I/O of IMPAM

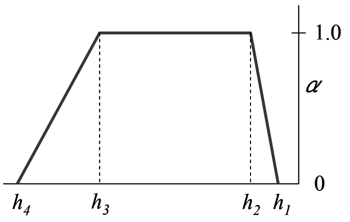


Fig.3. Function of Feddes

3.3 Data and parameters

3.3.1 Climate data

Climate data for 2070s that was used in this study was derived through RCM (Rregional Climate Model) downscaling of NCEP-reanalysis data with “Pseudo warming” method (Kimura and Kitoh, 2007). This method uses differential of climatology between present and future. Results of two GCMs (MRI-CGCM2 and CCSR/NIES-CGCM) were used to obtain the differential, and two datasets were generated. In the followings, the two climate datasets for 2070s will be called with name of the institutes that developed the GCMs: MRI and CCSR/NIES. The climate dataset delived through downscaling of NCEP-reanalysis data (called NCEP) was used for control runs.

Evaporation of MRI and CCSR/NIES is slightly larger than that of NCEP. Precipitation of MRI and CCSR is much less than that of NCEP during winter to spring (Fig.4).

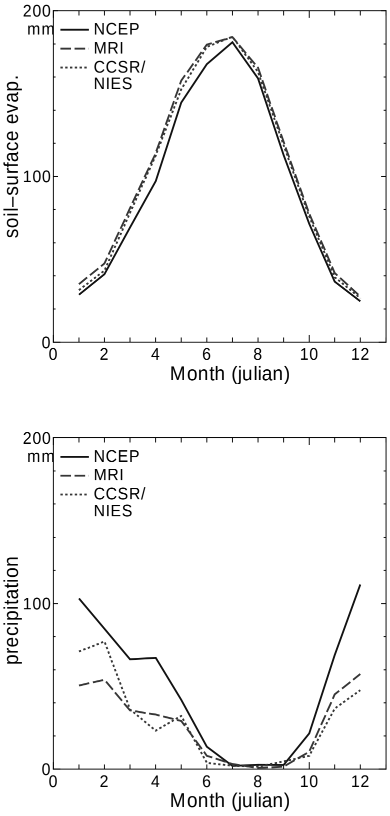


Fig.4. monthly precipitation and potential soil-surface evaporation (10-year average)

Soil-surface evaporation was calculated by Penman- Monteith equation

3.3.2 Water and crop management

Water and crop management depends on climate and the basin change scenarios that determine water requirement in the LSIP and available water resource. As two climate dataset and three basin change scenarios were used in this study, six water management and cropping patterns were assumed. Simulations were carried out with nine conbinations of climate and management dataset; one for control run (NCPPRS), two for impact assessment on the present management (MRIPRS and CSRPRS), six for climate and management changes (MRIAD1, MRIAD2, MRIAD3, CSRAD1, CSRAD2 and CSRAD3) (Table 1).

Crop pattern map for the base case (current situation) was rested of satellite data analysis by Dr. Suha Berberoglu and statistical data at 2002. Ratios of crop pattern under the adaptation scenarios 1, 2 and 3 under both the two projected climate (MRI and CCSR/NIES) based on results of economical analysis on relation between available water resource and farmers behavior by Umetsu et al. (2007) (Table 2). Amount of current water diversion to the LSIP and available water for the LSIP under the basin change scenarios scenarios that were used in Umetsu et al. (loc. cit.) was based on measurement by DSI and runoff-analysis by Fujihara et al (2007) respectively. Analysis of Fujihara et al. (loc. cit.) was besed on the same projeceted climate dataset as this study. Spatial cropping patterns (Fig.5) in assumed scenarios were made with a probability method based on the calculated crop ratios and spatial distribution pattern of crop in 2003 that was obtained through analysis of satelite data by Dr. Suha Berberoglu.

Nagano et al. (2005) reported amount of water supplied to a tertiary canal was tree times of net water requirement in the LSIP. As tertiary canals in the LSIP are lined or constructed with flumes, two-thirds of the water supply should mostly directly flow into drainage channels as tail water or infiltrate as application loss around an inlet of each farm-lot. Rotation irrigation is not practiced and water is supplied every canal throughout irrigation seasons. Ratio of delivery water requirement to the total should be quite large in the LSIP.

Based on Fujihara et al. (2007), Nagano et al.

(2005) and design conveyance efficiencies of the LSIP, parameters for water supply and delivery were set for present and assumed situations (Table 3).

Irrigation amount and schedule determined in the above processes were fed to IMPAM as a fixed schedule table.

The present command area in Table 3 does not contain Phase IV area (20,400ha was irrigated in this study). It was assumed that unit amount of net water requirement and application losses for phase IV are same as other areas. These water requirements for Phase IV area 0.23 x10^9 m^3 is covered by tail water (0.57×10^9 m^3) in Table 1 while tail water in Ad.1 (0.46×10^9 m^3) was wasted to the sea uselessly.

Table 1 Codes for combination of datasets for simulations

	Present	Adaptation 1		Adaptation 2		Adaptation 3	
	PRSN	AD1M	AD1C	AD2M	AD2C	AD3M	AD3C
NCP	NCPPRS						
MRI	MRIPRS	MRIAD1M		MRIAD2M		MRIAD3M	
CSR	CSRPRS		CSRAD1C		CSRAD2C		CSRAD3C

NCP, and CSR stand for NCEP and CCSR/NIES respectively

Crop and water management at the 2003

ADxM/ADxC: Crop and water management for each scenario under climate MRI / CSR.

Table 2. Ratio of crops for each scenario (unit: %)

	Present	Adaptation 1		Adaptation 2		Adaptation 3	
	PRSN	AD1M	AD1C	AD2M	AD2C	AD3M	AD3C
Maize	52	33	51	41	63	10	31
Wheat + Maize II	12	0	0	0	0	0	0
Cotton	9	24	4	15	0	48	26
Melon	7	8	13	10	16	3	8
Orchard	14	30	29	30	29	32	30
Soy	2	0	0	0	0	0	0
Vegetables	5	4	3	4	3	6	5

Table 3 Annual water supply and delivery parameters

	Present*	Ad.1		Ad.2		Ad.3	
	PRS	AD1M	AD1C	AD2M	AD2C	AD3M	AD3C
From the Seyhan R.	1.56×10^9 m^3	1.82×10^9 m^3	1.82×10^9 m^3	1.32×10^9 m^3	1.31×10^9 m^3	0.98×10^9 m^3	0.97×10^9 m^3
Well water						0.28×10^9 m^3	0.28×10^9 m^3
Irrigated area	93,500 ha	93,500 ha		113,900 ha		113,900 ha	
Irrigation (net)	0.50×10^9 m^3	0.59×10^9 m^3	0.59×10^9 m^3	0.70×10^9 m^3	0.69×10^9 m^3	0.66×10^9 m^3	0.61×10^9 m^3
Others							
Application losses	0.34×10^9 m^3	0.39×10^9 m^3	0.39×10^9 m^3	0.27×10^9 m^3	0.29×10^9 m^3	0.22×10^9 m^3	0.23×10^9 m^3
Conveyance losses	0.16×10^9 m^3	0.38×10^9 m^3		0.11×10^9 m^3		0.10×10^9 m^3	
Tail water	0.57×10^9 m^3	0.46×10^9 m^3		0.21×10^9 m^3		0.21×10^9 m^3	

* Net irrigation requirement (0.10×10^9 m^3), application losses (0.07×10^9 m^3) and conveyance losses (0.06×10^9 m^3) for Phase IV area is *not* included for PRS in this table.

3.3.3 Soil and geological parameters

Silt with saturated water conductivity 0.26 m $s^{-1}$was given for the whole area based on field measurements.

Transmissivity of groundwater was set to 4000m^2d^{-1} for the whole study area.

3.3.4 Other settings for calculation

Boundary conditions

Dirichlet boundary conditions were used for the northern and southern boundaries. Groundwater level at northern boundary that is along the foot of mountains was fixed about 5 m below the ground surface. That at southern boundary that is the coastline was 0 m in simulations with the present climate and 0.8 m in those with the projected climate. Neumann condition (zero flux) was assumed for eastern and western boundaries. As initial groundwater level is unknown, five-year spin-up was conducted before calculation for 1994 – 2003 in each case.

Resolutions

Spatial resolution was 1000m×1000m. Time step for crop growth and water management was 1-day. Other hydrological elements were calculated with 0.5 day time step.

4. Results and discussion

4.1 Control run

Temporal variation pattern of groundwater level and spatial distribution pattern of water logging areas (Fig.6) fairly agreed with observed ones.

Ratio of actual transpiration (T_a) to potential transpiration (T_p) was 0.7 – 1.0 in most of the area (Fig.7). Restriction of transpiration occurred mostly because water logging.

Through northern and southern boundaries, about 100mm/year ($1.8\times10^9 m^3$/year) of water was supplied constantly in the control run. It should be mostly recharge at the northern boundary where hydraulic gradient was much steeper.

4.2 Changed climate × present management

Groundwater level in MRIPRS and CSRPRS were lower than that in the control run (NCPPRS) especially in winter because of decreased precipitation (Fig.8). While CSRPRS showed more intensive fall of groundwater level in winter than MRIPRS, there was no significant difference between the two simulation results during and just after irrigation season (Fig.8). This suggests that decrease of precipitation affect groundwater level only in winter when irrigation with vast surplus is applied.

Although 0.8 m higher sea water level was given to the simulations with projected climate data, groundwater rise was seen within 3 km at most along the coastline.

Same amount of irrigation was applied in NCPPRS, MRIPRS and CSRPRS although the latter two cases have more potential evaporation and less precipitation. No significant difference in T_a/T_p ratio however was seen among the three cases.

4.3 Changed climate × assumed scenarios

4.3.1 Groundwater

AD1 simulations resulted lower groundwater level in project phase IV area (the lowest part of the area) and higher groundwater level in phase I – III areas (Fig.10a). Fall of groundwater level should be because of abandon of irrigation. Raise of groundwater level should be result of increase of seepage loss.

AD2 simulations showed fall of groundwater level throughout the area because of less seepage loss (Fig.10b).

Although application loss and conveyance loss of AD3 were less than those of AD2 and water requirement for each crop is common in AD2 and AD3, no significant difference in groundwater level was not seen between AD2 and AD3 (Fig.10a, b). Due to well water usage, AD3 had more total available water than AD2, and it had more high water requirement crops in ratio. Although water requirement for each crop was calculated based on evapo-transpiration, certain percentage of applied water infiltrated deeper zone inevitably in case of surface irrigation.

Inflow amounts at the boundaries were 150mm, 140mm and 170 mm in MRIPRS, MRIAD1 and MRIAD2 respectively while it was 100 mm in NCPPRS. As inflows may decrease in the future because of decrease of recharge in the upstream, actual groundwater levels may be lower than those projected in this study.

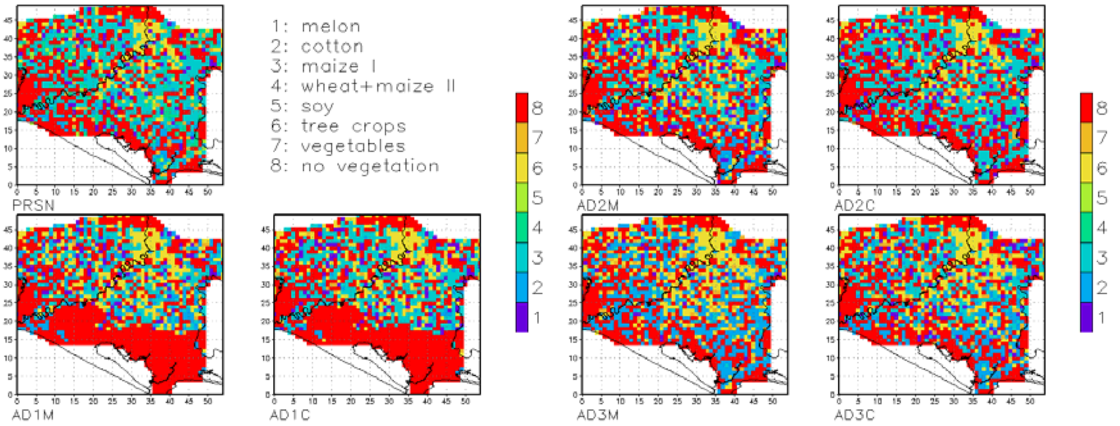


Fig. 5. Spatial distributions of crop patterns

Grid size: 1000m × 1000m

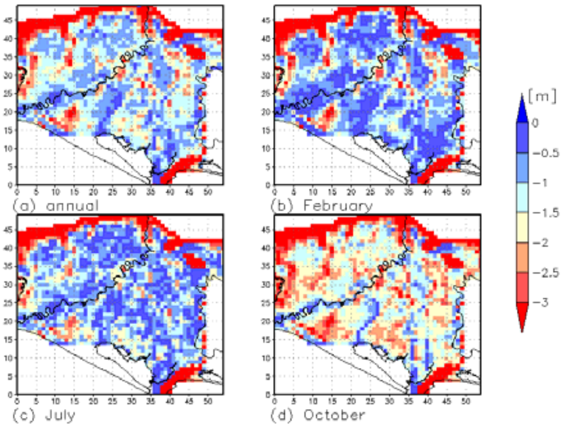


Fig. 6. Groundwater depth in NCPPRS

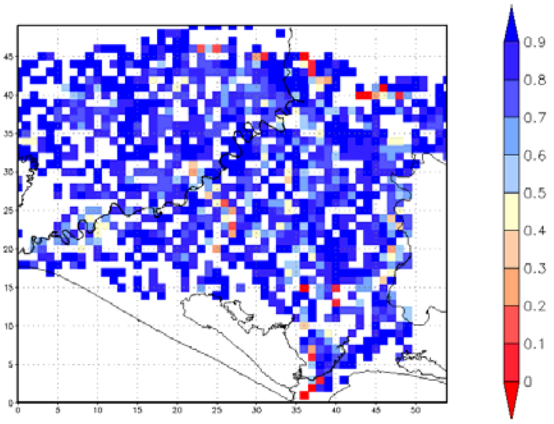
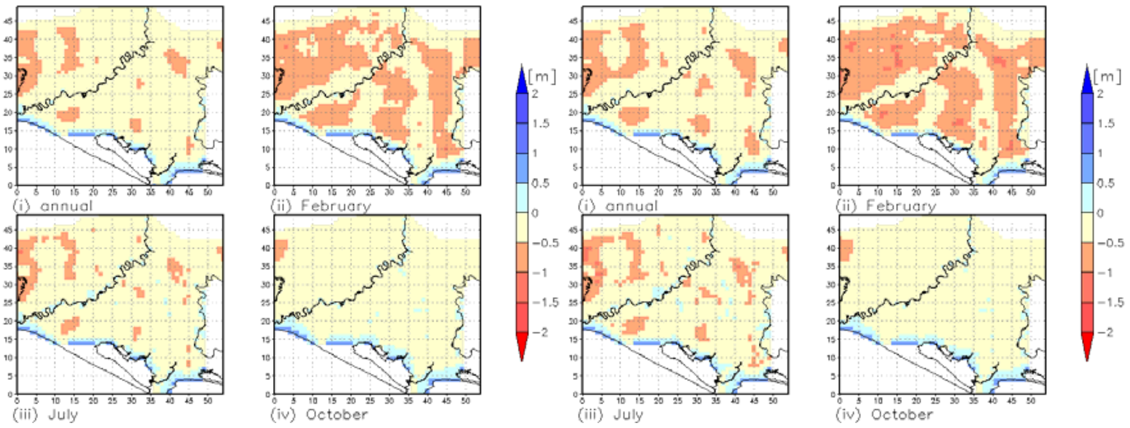


Fig. 7. Annual Ta/Tp in NCPPRS (10-year mean)



(a) MRIPRS – NCPPRS

(b) CSRPRS – NCPPRS

Fig. 8. Differential of groundwater level (annual mean and monthly mean of February, July and October) with the two climate dataset

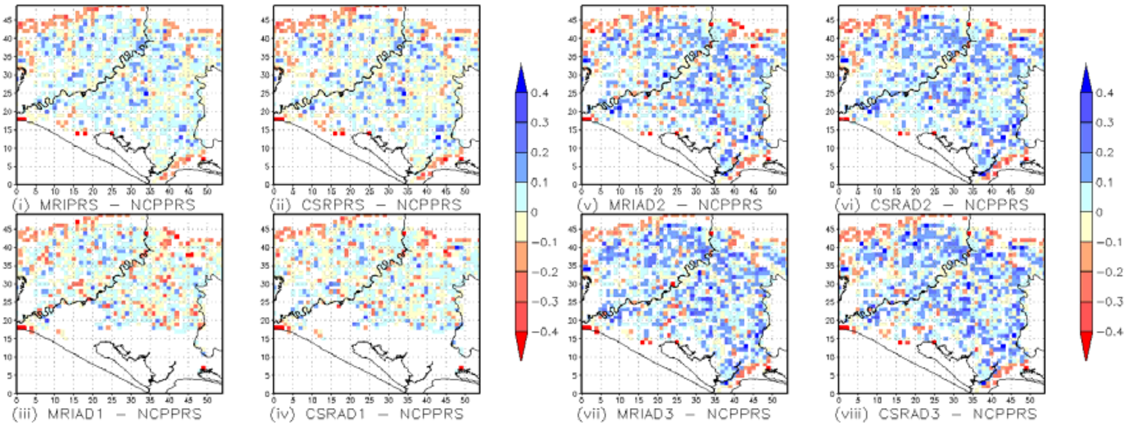
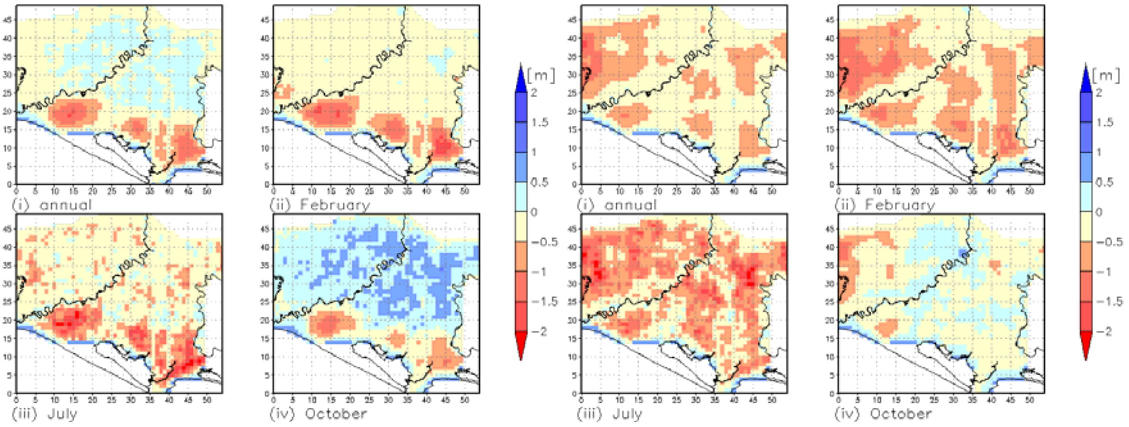
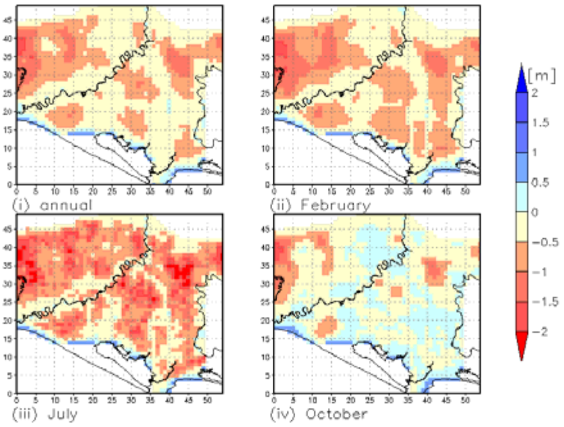


Fig. 9. Differential of annual mean of Ta/Tp ratio



(a) CSRAD1 – NCPPRS

(b) CSRAD2 – NCPPRS



(c) CSRAD3 – NCPPRS

Fig. 10. Differential of groundwater level (annual mean and monthly mean of February, July and October)

4.3.2 T_a/T_p ratio

No significant difference of T_a/T_p ratio (increase of water stress) was seen among the control run, AD1 and AD2 runs (Fig.9 iii - viii). As far as groundwater level is not changed much, soil moisture condition that determines T_a/T_p ratio is not changed drastically. Root zone was kept wet as water table was located near the ground surface in the LSIP. AD3 simulations resulted increase of T_a/T_p ratio because of fall of groundwater level.

5. Conclusions

Direct effect of global warming on hydrology in the LSIP may be not large enough to affect agricultural production in the LSIP. Effect of sea level rise might be limited within the range of a few kilometers from the coast line where there is little crop field. If changes in water and crop management are induced by global warming however, they might be much larger.

This study used two climate dataset derived from two GCMs. Simulations with the two datasets showed substantially same direction of hydrological changes in the LSIP.

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