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Controlled drainage, to cope with the adverse impacts of climate change on paddy field's hydrology: a simulation study using the drainmod model, Kunshan, China

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A study was carried out to assess the DRAINMOD model in predicting the role of Controlled Drainage strategies and Drain Spacing scenarios in the paddy field. The DRAINMOD model was simulated for the current (2018), Near Future 2021 to 2060 and Far Future 2061 to 2099 in the Kunshan region, China. Potential Evapotranspiration was estimated by the Thornthwaite method. The model performed good agreement in predicting paddy's water balance for the period of 2017-18. Also, Projections of the future climate in the Kunshan region, showed that there will be a decrease in the annual precipitation during rice-growing seasons for both Near Future (2021-2060) and Far Future (2061-2099). The DRAINMOD model was utilized to evaluate the impact of such a future decrease in precipitation on ground Water Tables Depth. Compared to the rice-growing season of 2018, DRAINMOD simulations showed that future Water Table Depths will drop by 38% to 40% for both the Near Future and Far Future under the Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. Such future remarkable drop in Water Table Depths may affect rice yield in the study region. The future water balance in the study area was re-simulated after replacing conventional drainage with Controlled Drainage and an increase in the drain spacing. Simulations revealed that practicing Controlled Drainage and an increase in drain spacing mitigated the future drop in Water Table Depths, thus ensuring better soil moisture conditions for rice. Therefore, Controlled Drainage approaches have the potential to cope with the adverse impacts of climate changes in the paddy fields.
Keywords: Climate change, control drainage drainmod, hydrology kunshan, paddy.

INTRODUCTION

Rice (*Oryza sativa L.*) is a prime agricultural crop and nourishes almost 50% of the world's population (Tan *et al.*, 2017). Also, this crop is considered an important diet crop in China, approximately an area of 30 million hectares is being engaged with rice fields (Huang *et al.*, 1999). In the interest of facing food increasing demand to fulfill the need for a rising population, rice yield output must be increased up to 70% by the mid of this century (Prosekov and Ivanova, 2018, Hameed *et al.*, 2019a). Because of environmental deprivation, transplanted rice's productivity became vulnerable (PENG, 2014, Rahim *et al.*, 2019). To attain the potential of more rice production, improvement in field managing planes are important (Hameed *et al.*, 2019b).
Since the late 19th century, China's most noticeable climate behaviour was the astonishing rise in temperature (Li *et al.*, 2010). The average global environmental temperature increased by 0.85 °C from 1880 to 2012. Moreover, if this warming trend continues, then at the end of 21st century the global average temperature will increase by 0.3-4.8 °C (Stocker *et al* ., 2013). Simultaneously, as global climate change, China is more affected by climate change, and the average surface temperature from 1908 to 2007 has increased by 1.1 °C (Jianping, 2015). The impact of climate change is usually high and sensitive to crop production and utilization of water resources (Peng *et al.*, 2004, Huntington, 2006). Despite the increase in the importance of industries, agriculture still has a fundamental role, especially in China (Piao *et al.*, 2010). In China especially lower reaches of Yangtze River basin are more famous for rice cultivation. In the mid of this century, the Yangtze River basin might suffer because of climate changes (Su *et al.*, 2008). Which could have unfavourable impacts on future water distribution thus

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could affect agricultural production (Sterle *et al.*, 2020). Several other studies in China have reported similar pattern of the adverse impact of climate changes affect the agriculture yield because of unfavourable rainfall pattern and rise in temperature (Zhao *et al.*, 2019, Ran *et al.*, 2018). Future prediction in climate changes are not even for example, in United State, Ohio is likely to face a significant rise in temperature and variation in several days with intense rainfall than Iowa by mid-century, (Singh *et al.*, 2009) predicted that future climate change would rise control drainage (CD) in Iowa. In the light of these opinions, recently, the researchers paid close attention to exploring climate change's effects on agriculture production, specifically growth, development, and crop productivity.

Crop water requirements depend on the balance between Evapotranspiration (ET) and rainfall. The climate change will alter the patterns of rainfall and temperature, ultimately it can disturb the crop water requirements (Rosenberg and McKenney, 1995). A study evaluate the influence of climate change by using the datasets of two General Circulation Models (GCMs), ECHAM4 and HadCM3, discovered that about 66% of the world's area equipped for irrigation will likely to suffer from high demands of crop water requirement (Döll, 2002). Under climate change scenarios, different researchers have used many crop models to simulate such impacts (Yao *et al.*, 2007). (Baethgen, 1997) used two models (ORYZA1 and SIMRIW), predicting rice yield in Asia and discovered that rice yield will decrease as temperature increases. Several other studies in China have reported the pattern of the adverse impact of climate changes affect the production yield because of unfavourable rainfall pattern and rise in temperature (Zhao *et al.*, 2019, Awad *et al.*, 2021). It's indispensable to adapt the study area to future climate changes to ensure high rice yield alongside saving the surrounding environment.

The DRAINMOD is an extensively applied model to estimate the drain discharge and Water Table Depths (WTDs) under various field conditions (Haan and Skaggs, 2003). This model facilitates making proper decisions in complicated situations where detailed field information is not possible. The application of DRAINMOD in South Africa (Malota and Senzanje, 2015), Israel (Sinai and Jain, 2006), Iowa (Singh *et al.*, 2006), Iran (Hassanpour *et al.*, 2011), and Iraq (Hamdi *et al.*, 2006), can reliably imitate CD System for various soils and weather conditions. Further, it can also be used for design of CD under shallow water table (Borin *et al.*, 2000).

Specific objectives are,

- To assess the performance of the DRAINMOD model in predicting the paddy's water balance in the Kunshan region for the period 2017-18, which represents the rice-growing season.
- To project future climate changes in the Kunshan region for Near Future (NF) (2021-2060) and Far Future (FF) (2061-2099).
- To simulate the future water balance and to assess the impact of climate change on future water balance in the target region.
- To assess the role of CD strategies and drain spacing scenarios on mitigating the adverse effects of climate change on future water balance in the Kunshan region

MATERIALS AND METHODS

Study Area: The experiment was conducted in Kunshan experimental research station, state key laboratory of Hohai University from June to October 2017/18. The experimental area was in the Taihu basin plain, a low-lying, densely covered water network. The climate was subtropical with heavy monsoon rainfall. The annual average temperature was 15.5℃ while annual rainfall was 1097.1mm and annual evaporation was 1365.9mm. The sunshine hours (Average annual sunshine) were 2085.9 h, and the annual average relative humidity was 83%. The local crop was rice and wheat rotation. The experimental area has dark-yellow hydromorphic paddy soil and heavy loam in texture. The bulk density of 0~30cm soil was 1.30 g/cm^3. Soil organic matter was 30.3 g/kg while total nitrogen, total phosphorus, total potassium were 1.79 g/kg, 1.4 g/kg, and 20.86 g/kg, respectively.

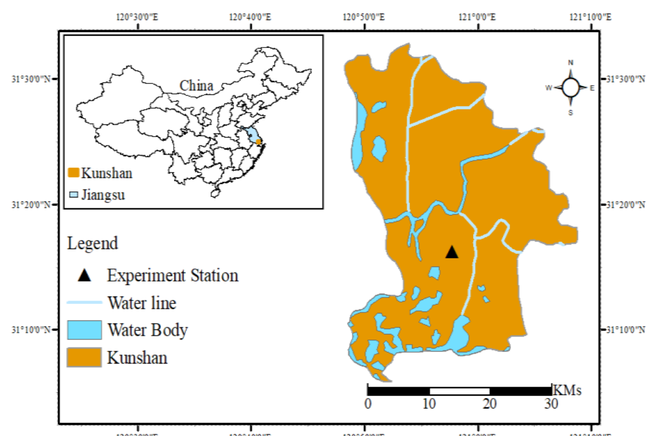


Figure 1. Kunshan Experimental Research Station, State Key Laboratory Hohai University

Test Design: The experiment was carried out in 6 standard impermeable plots of the Kunshan experimental research station. Each plot covered 150m^2 (10m * 15m) and was surrounded by an impermeable concrete wall having coated from inside. The gap between the two experimental plots was 0.4m. The 1-3 plot's drainage pipes (CD) were arranged perpendicular to the Conventional Drainage. The drain depth from the soil surface was 40cm below the field surface. An observation well was set near the drain, a water level control device, a water measuring weir, a water level gauge and an underground water level observation device were arranged at

Table 1. Soil Moisture in the Root Zone of Rice Control Irrigation.

Growth Period			Tillering Stage			Jointing and booting stage			
		Green period	**Early- stage**	**Mid Stage**	**Late**	**Early- stage**	**Late**	**Flowering**	**Maturity**
Irrigate water on limit	Percentage*		100%	100%	100%	100%	100%	100%	100%
	Water amount	25 mm	θs 1	θs 1	θs 1	θs 2	θs 2	θs 3	θs 3
Irrigate water under limit	Percentage*		70%	65%	60%	70%	75%	80%	70%
	Water amount	5 mm	70%θs1	65%θs1	60%θs1	70%θs2	75%θs2	80%θs3	70%θs4
Root Depth (cm)			0-20	0-20	0-20	0-30	0-30	0-40	0-40

Note: 1) The water content in the table is the average soil water content in the observation depth of the root layer, θs1, θs2, θs3, θs4 refer to the saturated water content of each stage, and all refer to the volume Water content**.** 2) Percentage * refers to the percentage of the saturated water content of the soil; the upper limit water content refers to the soil water content, which is composed of the percentage of the saturated water content and the saturated water content measured. 3)When the soil moisture reaches the lower limit of soil moisture content, irrigate to the upper limit. Calculate the actual irrigation according to the difference between the actual moisture content and the saturated moisture content of the root layer.

Table 2. Drainage Measurement for soil depth.

Drain types	**Weir-type**	**Flow rate equation**	**Water level gauge**	**Data recording**
Control drainage	30° thin wall triangular weir	$Q=373.2H^{2.5}$ (l/s)	Odyssey water level gauge (1m gauge)	1 time/0.5h
Conventional drainage	45° thin wall triangular weir	$Q=571.4H^{2.5}$ (l/s)	Hobo water level gauge	1 time/0.5h

Note: H is the difference between upstream water level of weir (measured by water level gauge)

Table 3. Details of the Four Climate Models.

Climate Centre	**Model**	**Resolution of the model**
China Meteorological Administration, Beijing Climate Centre	BCC - CSM1.1 (m)	1.125 ° x 1.125 °
University of Tokyo (Institute of Atmospheric and Oceanographic Research, National Institute of Environmental Research)	MIROC ESM – CHEM	2.8125 ° x 2.8125 °
Geophysical Fluid Dynamics Laboratory	The GFDL - ESM2M	2.5 ° x 2 °
Hadley Meteorological Centre	HadGEM2 – ES	1.875 ° x 1.24 °

the CD outlet. The water measuring weir and water level gauge were set at the drain outlet.

Data Collection

Meteorological Data 2017/18**:** The weather data including daily precipitation, maximum (Tmax), and minimum (Tmin) temperatures were observed during July-September 2017/18. The irrigation depth (mm day^{-1}) was measured (Table 1) and added to the rainfall. Potential Evapotranspiration (PET) was estimated by the Thornthwaite method.

Historical and Future Meteorological Data**:** The historical meteorological and General Circulation Models (GCMs) climate model data was used in the simulation. That was acquired from the China meteorological administration centre, which mainly includes the daily Tmax, Tmin, average temperature, and precipitation.

GCMs data were obtained from the Coupled Model Intercomparison Project phase 5 (CMIP5) of the World Climate Research Programme (WCRP). CMIP5 brings together more than 50 global climate models, providing an important database for the Intergovernmental Panel on Climate Change (IPCC's) fifth assessment report (AR5). Compared with the third phase of the coupled model comparison plan (CMIP3), the CMIP5 model is more complex. It introduces earth system models such as biogeochemical processes to simulate the global carbon cycle process for the first time. The resolution of the CMIP5 climate model was generally higher. The description of atmospheric physical processes was exemplary, and more meteorological elements output was provided. Comparatively, the CMIP5 GCM data adopted a new generation of greenhouse gas scenarios (i.e., Representative Concentration Pathways RCPs). The quantile mapping or cumulative distribution function (CDF) matching method was used in adjusting GCMs distribution outputs to find the transfer function between observations and model outputs (Wang *et al.*, 2017). In this study, two climatic scenarios (RCP 4.5 and RCP 8.5) of four different climate models, (MIROC-ESM-CHEM, HADGEM2-ES, BCC-CSM1.1 (m) and GFDL-ESM2M) were simulated. Details of the selected GCMs are provided in Table 3. Moreover, GCMs simulations were split up into two-time horizons, i.e., Near Future (NF) from 2021 to 2060 and Far Future (FF) from 2061 to 2099.

Infiltration Parameters**:** The infiltration was simulated by the Green-Ampt equation embedded in DRAINMOD.

$$f = \frac{A}{F} + B \ldots\ldots (1)$$

Where, f is the infiltration rate (cm hr^{-1}), F is accumulated infiltration (cm), A and B are Green-Ampt infiltration coefficients, B is the vertical saturated hydraulic conductivity (cm hr^{-1}).

The value of B at the upper layer was taken as K_{sat} of the upper layer and at the bottom layers were slightly less than K_{sat} of the bottom soil layers. Further calculations of A and B at different WTD were determined as per the procedures explained in the DRAINMOD reference report (Skaggs, 1980).

Table 4. WTDs versus Green-Ampt infiltration parameters were used for calibration of the model.

Sr.	WTD (cm)	A (cm hr^{-1})	B (cm hr^{-1})
1	10	0.08	0.57
2	20	0.12	0.57
3	40	0.17	0.57
4	60	0.20	0.57
5	80	0.22	0.57
6	100	0.23	0.57
7	150	0.41	0.57
8	200	0.41	0.57
9	1000	0.41	0.57

***Drainage System Design Parameters*:** From the experimental site, various inputs of drainage system design were collected. That includes drain depth, impermeable layer from the soil surface, the distance between two drains, effective drain's radius, equivalent depth from drain to permeable layer, drainage coefficient, initial WTDs, surface storage along with other parameters were collected.

Table 5. Drainage design system parameters used for calibration of DRAINMOD.

Sr.	Drainage design system parameters	Parameters value (cm)
1	Drains Depth (from soil surface)	40
2	Drains Spacing	1000
3	Effective radius of drains	5
4	Depth of impermeable layer from soil surface	190
5	Depth from drain to permeable layer	83.5
6	Initial depth to water table	30

Description of The DRAINMOD 6.1 Model: In 1980, Dr. Wayne Skaggs developed the one-dimensional computer simulation model, i.e., DRAINMOD. It emphasizes drainage in soils and estimates the impact of drainage on WTDs, soil water regime, and yield of the crop (Skaggs, 1980). The latest version, DRAINMOD 6.1 provides a graphical interface that facilitates easy input of data sets, running model simulations, and showing model outputs.

DRAINMOD model utilizes functional algorithms to estimate the hydrological parameters in soils having shallow water tables (Skaggs *et al.*, 2012). Soil, weather, and crop information are the essential inputs to the model. Whereas daily WTDs, infiltration, drainage, and runoff are its outputs. These results are mainly calculated from the water balance of a unit soil section positioned on mid-way among two drains as given in the DRAINMOD reference report (Skaggs, 1980). The daily WTDs at various drain spacings were calculated from the steady-state Hooghoudt's equation (Hooghoudt, 1940)

$$q = \frac{4K_{sat}h(h+2d_e)}{L^2} \text{.... (2)}$$

Here, L is drain spacing (m), q is drainage (mm day^{-1}), K_{sat} is saturated soil hydraulic conductivities (m day^{-1}), d_e is equivalent depth (m), h is hydraulic head among two drains (m).

Drainmod Evaluation: Both graphically and statistically the DRAINMOD was evaluated. The simulated and measured values were organized alongside the time series for the graphical approach. Therefore, the simulated response of the DRAINMOD can easily be quantified visually. In another approach, the similarities between the simulated and measured daily ground water-table depths and drainage discharge were statistically quantified by calculating the correlation coefficient (R^2), Average Absolute Deviation (AAD), and Root Mean Square Error (RMSE). Statistically, these parameters were utilized to estimate the model capabilities; the AAD is the indicator of quantitative dispersion between the simulated and measured values. The correlation coefficient represents an agreement between the simulated values and measured values.

***Statistical Analysis of DRAINMOD*:** The daily WTDs and corresponding drain discharges from drain spacing (DS) of 100 cm and drain depth (DD) of 40 cm (2018 year) data were used for calibration. The DRAINMOD calibration was based on the trial and error method (Dayyani *et al.*, 2010), by changing few input parameters, until the best resemblance among simulated data and observed data was achieved. The time series data for WTD and drainage were simulated and compared to the observed data. The R^2, RMSE, AAD (Hameed *et al.*, 2019b) were calculated using Equations 3, 4, and 5, respectively.

$$R^2 = \frac{(\sum_{i=1}^{n}(O_i-\bar{O})(P_i-\bar{P}))^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2\sum_{i}^{n}(P_i-\bar{P})^2} \text{.... (3)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{n}} \text{....... (4)}$$

$$AAD = \frac{\sum_{i=1}^{n}|p_i-o_i|}{n} \text{............ (5)}$$

where Pi = daily predicted value; Oi = daily observed value; n = number of days; i = index of days

Table 6. Statistical Analysis

		AAD (cm)	R^2 (%)	RMSE (cm)
Calibration	Water table	8.58	0.84	11.54
	Drainage	0.10	0.75	0.15
Validation	Water table	6.31	0.89	7.76
	Drainage	0.13	0.81	0.17

RESULTS

DRAINMOD Calibration and Validation

DRAINMOD Calibration: We adjusted uncertain and sensitive parameters to abate the difference between the simulated and observed CD and WTDs of 2018. For model calibration, specific parameters and their ranges were designated based on the sensitivity and analyses earlier conducted for the model as described in the literature (Wang *et al.*, 2006a) . The model was calibrated for one season of paddy field. The DS of 100cm and DD of 40cm were used for calibration. Figure 3 shows a good agreement between the observed and predicted daily WTD, CD in the calibration. For WTD, the AAD value was 8.58 cm. Also, The RMSE for WTD was 11.54 cm and the R^2 was 0.84%.

During calibration, the R^2, AAD, and RMSE values for CD were 0.75%, 0.10 cm, and 0.15 cm, respectively. Statistically, observed and simulated drain discharge hydrographs showed good agreement having a high R^2 of 0.75%.

Validation of DRAINMOD: The DRAINMOD model was validated using the calibrated dataset by comparing predicted and observed results for one growing season of 2017 despite further adjustment of the model inputs. While simulating WTD during the validation period, the model showed good performance (Figure. 4a). The summary of statistics explained the model performance in Table 6. The validation results show that the simulated and observed WTD variations are correlated very well, where the R^2 is 0.89% and AAD is 6.31 cm.

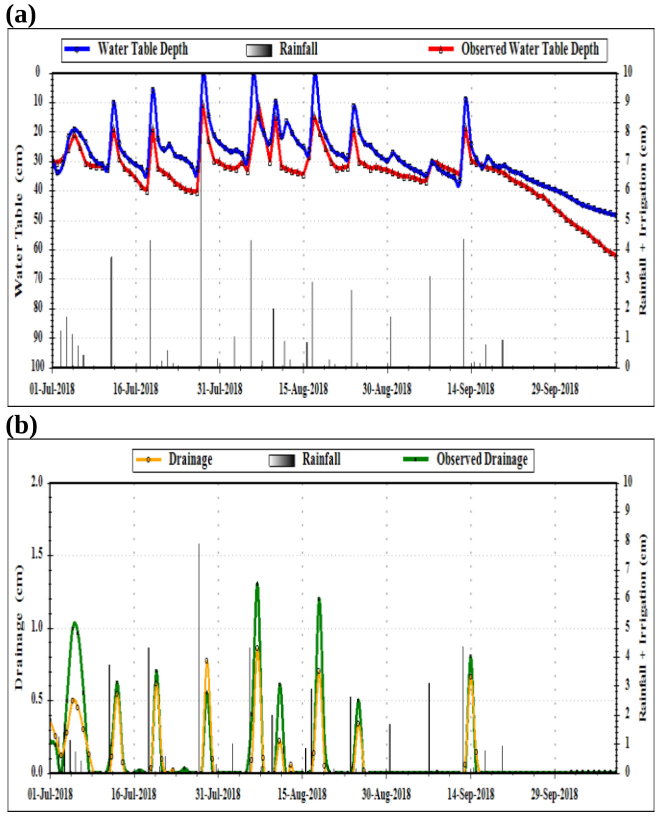


Figure 3. DRAINMOD Graphing Utility Program's Graph for Ground WTDs and Control Drainage (Calibration)

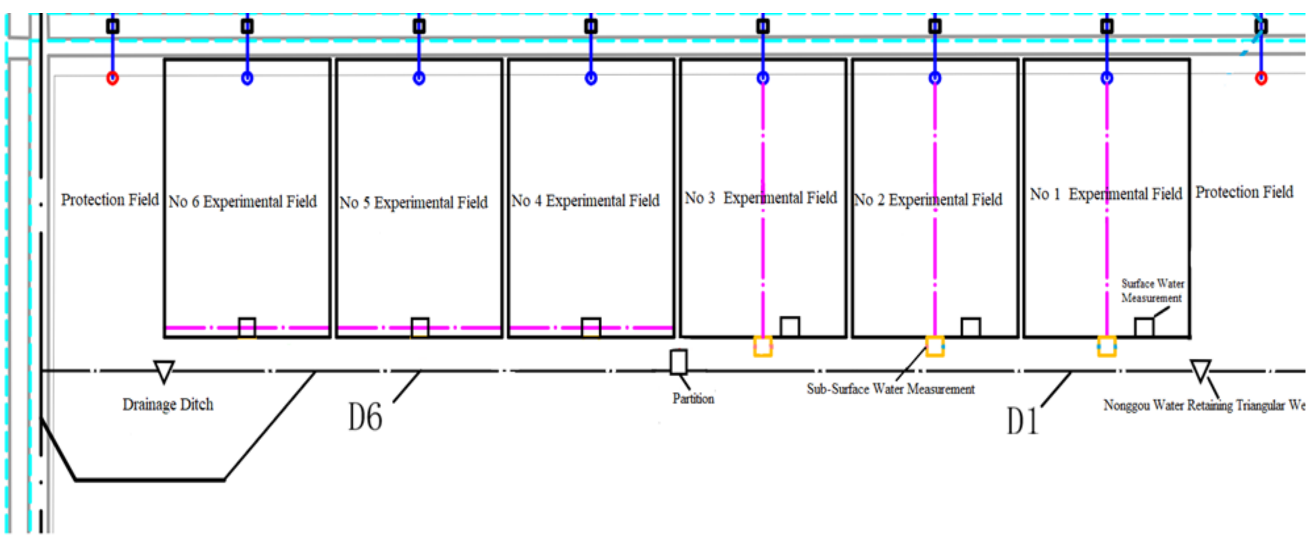


Figure 2. Test Design in the Kunshan Experimental Research Station

While predicting drainage during the validation phase, the DRAINMOD model performance results are shown in hydrographs (Figure. 4b). The correlation between simulated and observed drainage discharge shows good agreement. Statistically, the relationship between the simulated and observed drainage is significant, having R^2 value of 0.81%. Similarly, a strong correlation was reported between simulated and observed drain discharge, with R^2 value of 0.80% during the validation of the DRAINMOD model (Malota and Senzanje, 2015).

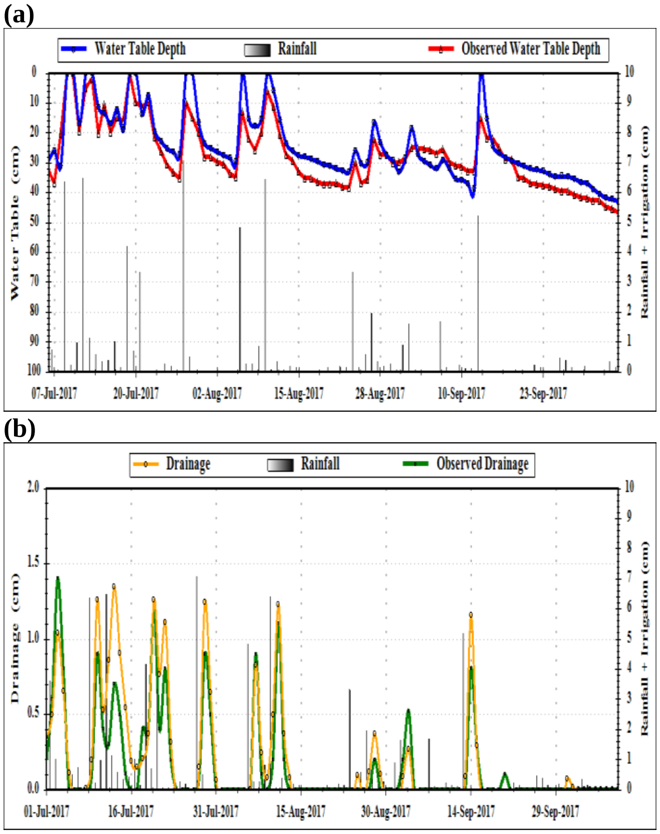


Figure 4. DRAINMOD Graphing Utility Program's Graph for Ground WTDs and Control Drainage (Validation)

Climate Change Future Scenarios (NF 2021–2060 and FF 2061-2099): Due to the uncertainty of climate models, it is difficult for a single climate model to provide the best estimate of all climate factors for changing climate conditions. Therefore, the Bayesian model average method (BMA) was used for multiple climate models in this study.

In general, for climate change studies, the longer the BMA baseline training period, the better the future simulation results are expected. In this study, a baseline period of 50 years (1961-2010) was used to train the BMA weights of the four climate models. Future climate models data [Near Future (NF) 2021–2060 and Far Future (FF) 2061-2099] were used under RCP 4.5 and RCP 8.5 scenarios to simulate the DRAINMOD model at the Kunshan site.

BMA data of different models were used for future simulation to check Paddy's field hydrology response to climate change. The BMA data presented a good correlation and low uncertainty as compared to single climate model data.

Precipitation and Temperature Changes Relative to Base Period: Almost all GCMs models projected an increase in mean daily temperature for the 21st century (Table 4). In NF under the RCP 4.5, the mean daily Tmax and Tmin will be stabilized while for FF under RCP 8.5, the Tmax and Tmin projected a sharp rise. The mean Tmax for the NF will be increased by 4.4°C and 6.3°C under RCP 4.5 and RCP 8.5, respectively. In comparison, the mean Tmax for the FF will rise by an average of 5.2°C under RCP 4.5 and 9°C under RCP 8.5 scenario. Also, the same trend was exhibited for Tmin.

Table 7. Changes of Temperature (Tmax and Tmin) and Precipitation (P), in the future scenarios relative to the baseline (Historical).

Scenario	Historical (1960-2010)		Near Future (NF) (2021-2060)		Far Future (FF) (2061-2099)	
Temperature (°C)	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax
RCP 4.5	21.8	28.5	1.2	4.4	2.0	5.2
RCP 8.5	21.8	28.5	2.6	6.3	5.0	9.0
Precipitation (P)	mm		(%)		(%)	
RCP 4.5	478.9		-44.1		-36.0	
RCP 8.5	478.9		-48.7		-47.2	

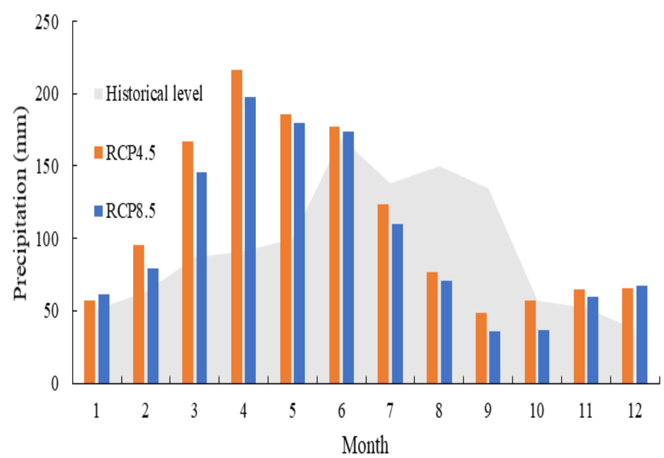


Figure 5. Monthly average of precipitation of Kunshan, station (2021-2099) under two scenarios. Histograms represent the average precipitation of two (RCP 4.5 and 8.5) scenarios and historical average precipitation.

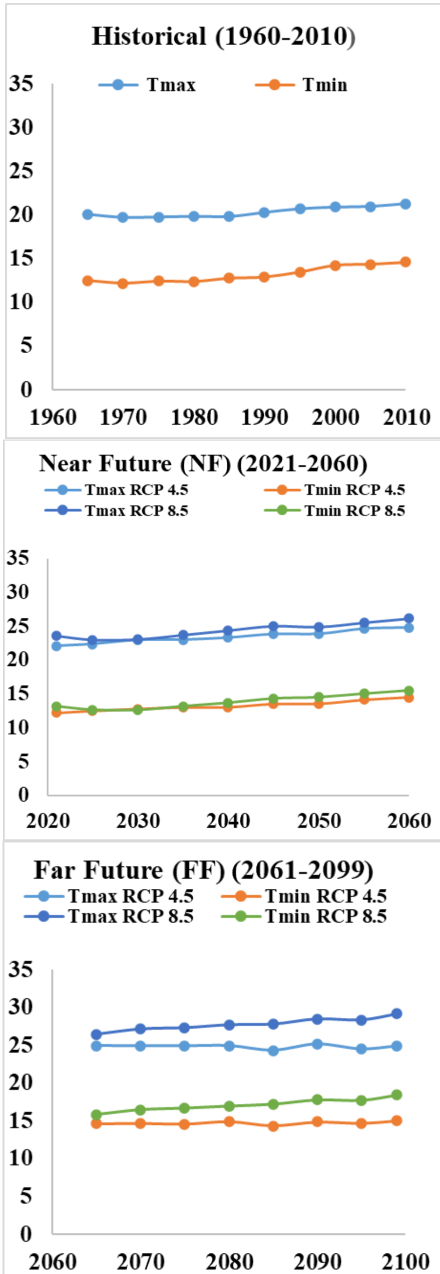


Figure 6. Changes in the Tmin and Tmax compared to the baseline (Historical) values, under RCP 4.5 and 8.5.

The Effect of Climate Change on Future Hydrology under Conventional Drainage and Control Drainage (CD) in the NF 2021–2060 And FF 2061-2099: Figure 7 represents the climate change impact on the Water Table Depths (WTDs), surface runoff, drainage discharge, and infiltration under conventional drainage. Despite projection, there is an overall increase in the future intensity of precipitation and a decrease in the future seasonal precipitation (Paddy Season). The DRAINMOD simulations projected an intensive increase in the WTDs. As shown in the Figure 7, almost a 40 % increase was predicted in the WTDs among all scenarios.

According to the model simulation, there will be a drop in annual future infiltration rates under all scenarios. The highest relative percent decrease for infiltration rate was about 40% in Figure 7 under RCP 8.5 (NF). Also, simulations showed a significant decrease in drainage in both NF and FF. The highest decrease of 61% in the drainage discharge was predicted in the NF for RCP 8.5. The DRAINMOD results showed that there would be a 99% decrease in runoff rate in two scenarios under RCP 4.5 (FF) and RCP 8.5 (NF).

(a)

(b)

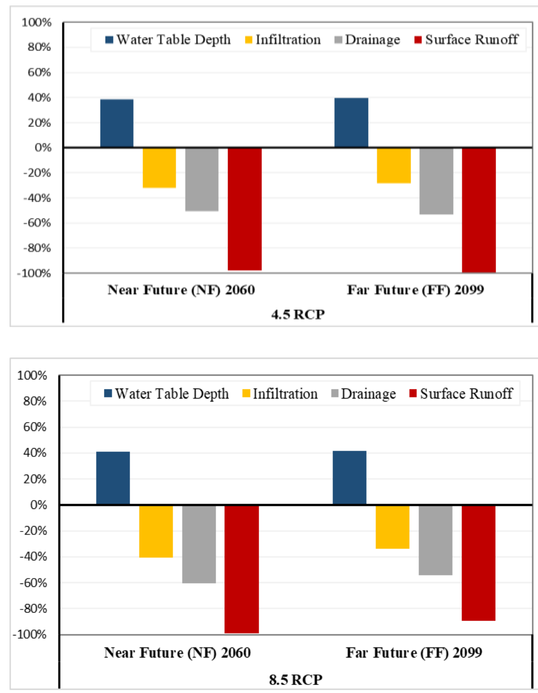


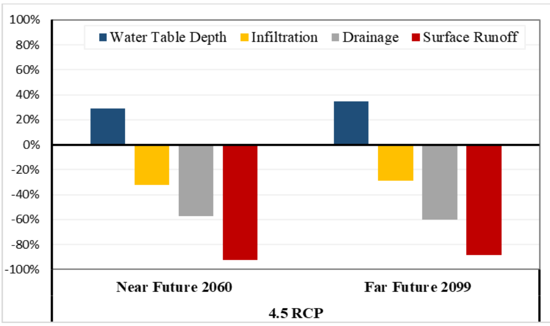
Figure 7. Effect of climate change on Future Hydrology under Conventional Drainage compared to baseline conditions.

Figure 8 represents the climate change impact on the WTDs, drainage discharge, surface runoff and infiltration under CD. Despite projection, there is an overall increase in the future intensity of precipitation and a decrease in the future seasonal precipitation (Paddy Season). The DRAINMOD simulations projected the intensive increase in the WTDs. The highest increase in WTD of 40% was predicted in the FF of RCP 8.5. DRAINMOD model simulations showed that there will be a drop in annual infiltration rates under scenarios RCP4.5 and RCP8.5 for both NF and FF. The highest relative percent decrease of 35% in the infiltration rate was observed under RCP 8.5 for NF.

DRAINMOD simulations further showed a significant decrease in drainage in both NF and FF. The highest decrease in drainage discharge was found in the NF for RCP 8.5, which was about 65%.

Surface runoff is one of the significant parameters of soil water balance. Similarly, along with other hydrological components, DRAINMOD also calculates the surface runoff.

(a)



(b)

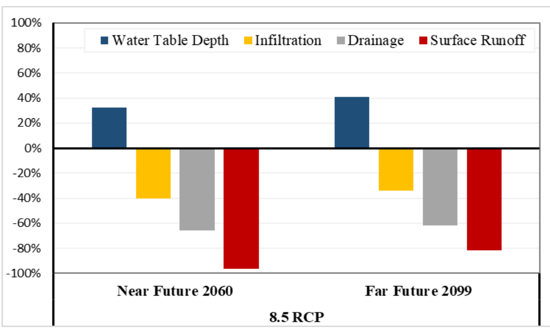


Figure 8. Effect of climate change on Future Hydrology under Control Drainage (CD) compared to baseline conditions.

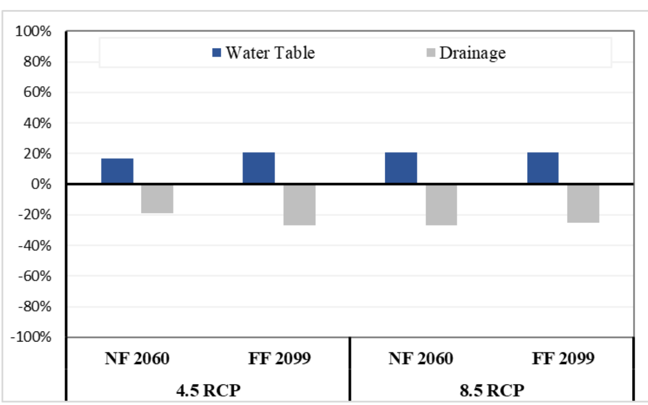


Figure 9. The Future Fate of Water Table and Drainage After Increasing Drain Spacing (2000 cm) under Control Drainage (CD) compared to baseline conditions.

Effect on Future WTDs and Drainage Discharge After Increasing Drain Spacing During Growing Season: In order to minimize the effect of climate change on CD, the distance between drainpipes was increased during simulation. According to (Carter and Camp, 1994) increasing the drain spacing will rise the WTDs. In addition, (Singh et al., 2006) suggested that the drainage increase with decrease drain spacing and vice versa. By increasing the drain spacing to 2000 cm, the simulations resulted in a significant rise in the WTDs and an increase in the drainage discharge.

DISCUSSIONS

(Skaggs *et al.*, 2012) described that when RMSE is < 10 %, 10-15 %, and 15-20 % indicates that the simulation performance of the model is excellent, good, and acceptable, respectively for successful simulation of WTDs with the DRAINMOD model. (Ebrahimian *et al.*, 2010) the RMSE and R^2 were 18.1 cm and 0.42, respectively to predict the WTDs with DRAINMOD. (Samipour and Naseri, 2010) also reported the R^2 and RMSE of 0.95 and 18.1 cm for prediction of WTDs simulation.

The model performed a good agreement while predicting WTD with AAD values 8.58 cm. In Figure 3, the WTDs showed good agreement with rainfall and irrigation, indicating that the WTD responded to the recharge through irrigation and rainfall. In addition, the model predicted the WTDs very closely with the observed WTDs during frequent rainy days. The model simulates well the fluctuations in midspan water table heights. The measured and simulated peaks are quite similar in the figures. However, the model is highly sensitive to rainfall patterns and the simulated WTDs are generally shallower than the measured values.

It is observed from Figure 3 b that a perfect correlation between the observed and simulated drainage discharge hydrographs can be deduced. The DRAINMOD drainage discharge simulation was excellent with RMSE of 0.32 mm day^{-1} and R^2 was 0.71% (Ebrahimian *et al.*, 2010). The DRAINMOD drainage discharge simulation was excellent with RMSE of 0.32 mm day^{-1} and R^2 was 0.71% (Ebrahimian *et al.*, 2010). Similarly, (Singh *et al.*, 2006) reported that the index of agreement and model efficiency was 0.85% when evaluating DRAINMOD observed and simulated drainage discharge.

Generally, the water demand will be increased in the 21st century as the temperature increases. Different literature pieces have confirmed this result by combining a simple water balance model based on CMIP5 (De Silva *et al.*, 2007, Thomas, 2008, Wada *et al.*, 2013). More significantly, the future irrigation demand will also rise significantly because of the reduction in precipitation during the growing period, (Figure. 4). Special consideration should be given to future climate predictions. The future rainfall in China will increase under climate change conditions (Yin *et al.*, 2015). The precipitation predictions based on BMA weighted set climate model also showed an increasing trend in this study. However, during the rice-growing period, the precipitation showed a decreasing trend in the average annual rainfall (Figure 4) in the Kunshan station, leading to a sharp decrease in the future drainage, runoff, infiltration, and water table, while an increase in the irrigation water demand. Future climate projections illustrate long-term increase of annual Tmin and Tmax in RCP4.5 and RCP8.5, as shown in figure 5. Currently, for agriculture water management, much attention is given by the researchers to the CD outflows from drainage fields. The proper management of these outflows could improve the ground WTDs and soil moisture conditions. If the rainfall values are below the average then, it is said to be a drought condition (Hüseyin *et al.,* 2017). According to future climate scenarios in the Kunshan region, there will be a reduction in the precipitation during the paddy growing season. Moreover, a sharp rise in temperature would lead to an increase in the evapotranspiration rate. Ultimately, the crop will need more soil moisture. All those mentioned situations will lead to a drop in the WTD significantly.

DRAINMOD model simulations showed that there will be a drop in annual infiltration rates under scenarios RCP4.5 and RCP8.5 for both NF and FF. The highest relative percent decrease of 35% in the infiltration rate was observed under RCP 8.5 for NF. These results showed the same trend with the findings of (Caplan *et al.*, 2019), a 25-year experiment in the Kansas region [United State (US)], where the infiltration rate was reduced from 21% to 33%.

DRAINMOD simulations further showed a significant decrease in drainage in both NF and FF. The highest decrease in drainage discharge was found in the NF for RCP 8.5, which was about 65%, These simulations are consistent with the findings in Ohio (US), under CD. A Study (Williams *et al.*, 2015) showed an annual reduction from 8% to 34% CD practices throughout an eight-year in Ohio US. One of the Western Lake Erie Basin (US) studies found that CD sharply reduced by 40% to 100% throughout the study periods (Gunn *et al.*, 2015). Also, the same trends were presented by (Pease *et al.*, 2017), despite increases in the future projected precipitation. By mid-century, the CD was projected to decline by 12.3% and 14.3% in the RCP 4.5 and 8.5, respectively. By the end of this century, the CD is projected to be decreased by 14.5% under RCP 4.5 and 23.7% under RCP 8.5. Compared to the historical period, the CD is projected to significantly decline throughout the year in all seasons especially with the most significant decrease in autumn. In this study, the reduction in annual CD found contrasts from the conclusions of (Singh *et al.*, 2009) and (Dayyani *et al*., 2012), who reveal complete rises in annual CD discharge in Iowa and Quebec (US), respectively.

Surface runoff is one of the significant parameters of soil water balance. Similarly, along with other hydrological components, DRAINMOD also calculates the surface runoff. In this study, the DRAINMOD results showed that there will be a decrease in future runoff rate during the crop growing period, with a high relative percent decrease under RCP 8.5 (NF). Likewise, simulations under future climate scenarios (Awad *et al.*, 2021) showed that surface runoff will reduce by 25.3% to 23.6% under RCP 4.5 and 8.5, respectively.

The same trend was also indicated by (Singh *et al.*, 2009) that about 10% to 21% reduction was observed in the average annual surface runoff under the future climatic scenario. However, (Sojka *et al.*, 2020) showed a different trend under future climate scenarios that an increase in the rainfall intensity in the NF and FF climatic scenarios will increase the surface runoff from the fields

Hence, the findings in this study about a decrease in the future runoff will safeguard the improved quality of surrounding water bodies. Since the surface runoff always contains agricultural nutrients that are regarded as the major pollutant of surface water near agricultural fields. After applying the increase in drain spacing, the WTDs will rise in the future climate change. Also, this research showed that in response to changes in climatic condition, soil hydraulic properties can also changes overtime scales (Robinson *et al.*, 2016, Hirmas *et al.*, 2018). Variations in the soil hydraulic properties could themselves have consequences for biogeochemical processes such as soil carbon storage and nitrogen fluxes (Seneviratne *et al.*, 2010).

***Conclusion*:** Climate change, especially in China, is at the forefront of scientific problems and posing a severe challenge to development and mankind's survival. In China since the late 19th century, the most noticeable climate characteristic in the background of global warming, is the extraordinary rise in temperature. From 1880 to 2012, the overall surface temperature increased by 0.85 °C, which is the highest value in history. Despite the rising significance of industries, agriculture still has a vital role in guaranteeing the food security and welfare of humans, which is particularly correct in China.

The hydrology of paddy fields in the Kunshan region suffers from future climate change and extreme rainfall patterns. But, especially during the rice cropping period, the average annual rainfall in the Kunshan region decreased under RCP4.5 and RCP8.5 scenarios. In this study, the DRAINMOD model was utilized to evaluate the impact of such a future decrease in precipitation on ground Water Table Depths (WTDs). Compared to the rice-growing season of 2018, the DRAINMOD simulations showed that future WTDs will drop by 38% to 40% for both the NF and FF under the RCP 4.5 and RCP 8.5. Such future remarkable drops in WTDs may affect rice yield. The future water balance in the study area was re-simulated after replacing conventional drainage with Controlled Drainage (CD) and increasing the drain spacing. Simulations revealed that practicing CD and increasing drain spacing can mitigate the future drop in WTDs, ensuring better soil moisture conditions for rice. Therefore, CD approaches have the potential to cope with the adverse impacts of climate changes in paddy field.

These results further showed the dynamic role of CD strategies in managing potential impacts of climate change on future water distribution patterns in paddy fields. Furthermore, these findings will be compelling for modifying the future hydrology of paddy fields to the surrounding water bodies, mitigating the non-point-source pollution that endangers the surrounding water bodies in the study region.

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