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Modeling crop land soil moisture and impacts of supplimental irrigaiton in a rainfed region of Bangladesh

Pramod K. Pandey*, Sagor Biswas

Department of Population Health and Reproduction, University of Californian, Davis, USA;
*Corresponding Author: pkpandey@ucdavis.edu

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ABSTRACT

A robust water balance model has been tested for predicting soil moisture levels and supplemental irrigation requirement of a rainfed region of Bangladesh. The predictions were used for improving the understanding of the impacts of rainwater harvesting on rainfed agriculture. The climate data (*i.e.*, rainfall, temperature, evaporation, and evapotranspiration) were used as inputs for predicting the variations in soil moisture. Soil moisture levels under rainfed and supplementary irrigation conditions were compared. Results showed that rainwater harvesting *i.e.*, rain water storage tanks during rainy seasons can be potentially useful for storing rainwater, which can be utilized for enhancing crop land soil moisture during dry seasons for enhancing crop yield. The study presented here will be useful for improving and disseminating rainwater harvesting approaches for enhancing water availability in rainfed regions.

KEYWORDS

Rainwater Harvesting; Rainfed Crop Land; Supplemental Irrigation; Crop Yield

1. INTRODUCTION

It is required to increase the agricultural water availability in rainfed regions to enhance the global food production. Approximately more than 80% of the global crop land is rainfed, which produces more than 70% of global food productions currently [1-3]. For improving food production further, additional water resources capable of providing the irrigation to crop lands is required [4]. One option is increasing the facilities/structures for rainwater harvesting in the crop land itself [5,6]. In many rainfed regions, for instance, in Bangladesh, more than 76% of rainfall occurs in rainy season (May to October); however, a major portion of it losses as runoff. Due to insufficient water storages, farmers often face irrigation water shortages during dry seasons. Providing the facilities capable of storing the rain water during rainy season can potentially facilitate water availability for irrigation. Previous studies have shown that harvested rainwater in on-farm reservoirs during rainy season can enhance crop yield considerably [7,8]. Here we have exploited a water balance model [8] for calculating soil moisture and crop yield under rainwater harvesting facilities and without rainwater harvesting (*i.e.*, rainfed) for improving the understanding of rainfed agriculture and rainwater harvesting approaches.

2. METHODS

2.1. Study Area

The study area is shown in **Figure 1**. Jessore, a district situated in the southwestern part of Bangladesh (BD), receives about 1741 mm of annual rainfall. Nearly 76% of annual rainfall occurs from May to October. Out of that about 28% of the total annual rainfall occurs in the month of July. Temperature varies from 10˚C to 36˚C. Relative humidity varies from 72% to 86%, and wind speed varies from 0.76 to 4.6 m/s. The rainfall and temperature variations of the study area are shown in **Figures 2** and **3**. Average monthly evapotranspiration variation is shown in **Figure 4**.

2.2. Model

The model used in the study has been described elsewhere [8]. The model has two components: 1) water balance simulation for crop land; and 2) water balance simulation for water storage tanks. Water storage tanks receive water from upland catchment area of 5 ha (as runoff), and direct precipitation on tank's surface. The stored water in the tanks was applied as supplemental irrigation (when needed) to the crop land for enhancing

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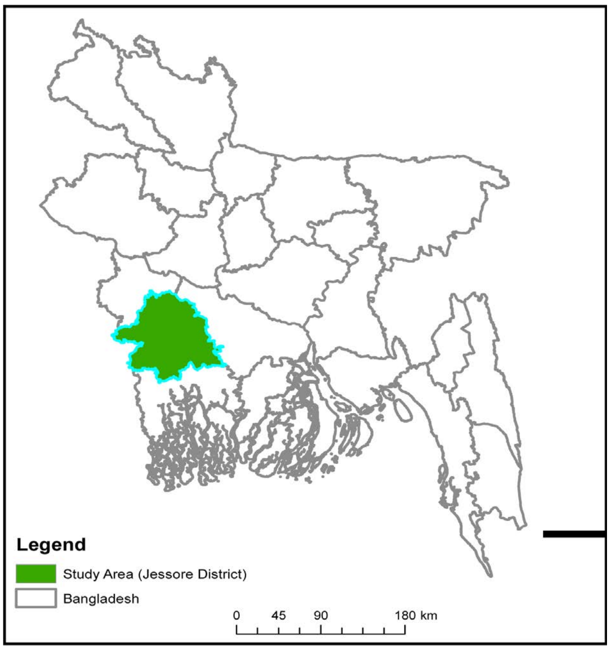

Figure 1. Study area (Jessore District, Bangladesh).

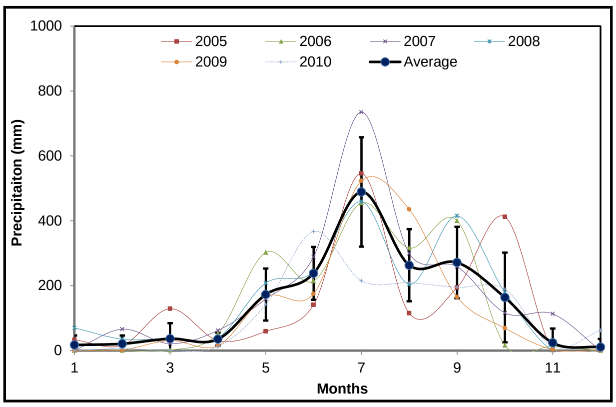

Figure 2. Precipitation (Jessore District, Bangladesh).

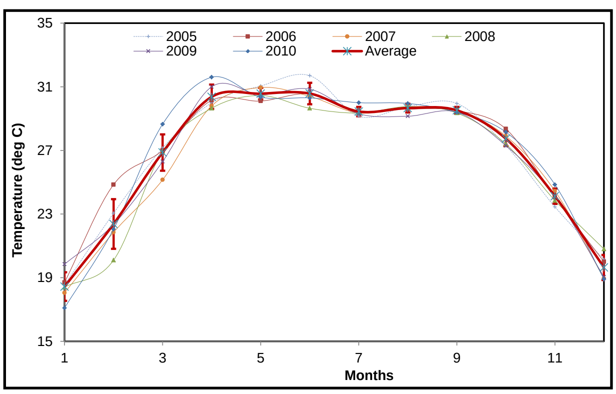

Figure 3. Temperature (Jessore District, Bangladesh).

soil moisture. In simulation, we used crop land area of 1 ha, reservoir area of 15% of the catchment area (*i.e.*, 0.8 ha).

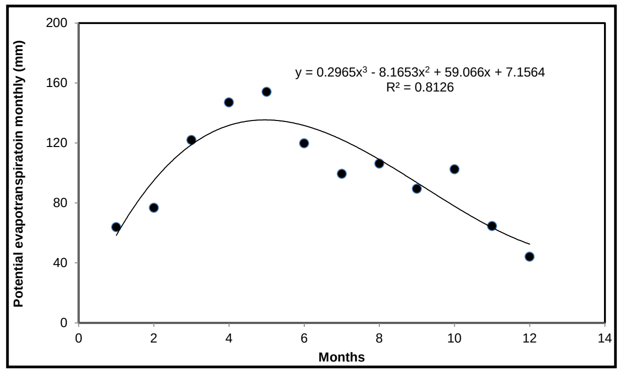

Figure 4. Potential evapotranspiration (Jessore, BD).

The model uses curve number for estimating the runoff from catchment to water storage tanks. Daily seepage, evaporation, and spill from the tank were simulated, and the simulation methods are described previously [5, 8]. Crop water requirement were predicted using readily available soil moisture and non-readily available soil moisture [8]. The crop coefficient of bean crop was used for simulating the crop water requirement at various crop growth stages as described previously [8].

The model requires multiple input parameters, which are described in two previous studies [5,8]. Readers are encouraged to preview the published studies for understanding the model's details. In this study, we used rainfall, temperature, and evapotranspiration data from the Jessore District of Bangladesh. The average monthly rainfall and min/max temperatures were obtained from Bangladesh Agricultural Research Council (BARC) [9]. Using the monthly data, we estimated daily data using polynomial equations (fitted on monthly data). Due to unavailability of evapotranspiration data of the Jessore District, we used neighboring climate stations for estimating the evaporation and evapotranspiration for the study area. The data of the neighboring stations (*i.e*. West Bengal, India) were obtained from two sources: 1) Indian Meteorological Department (IMD) [10], and 2) Hydrology and Water Resources Information System for India [11]. The climate data (*i.e.*, temperature and rainfall) of the location in India were compared with the Jessore District, and the data were comparable. For example, the annual monthly rainfall data had similarity of 78% and annual monthly temperature had the similarity of 87%. After combining the deviation of rainfall and temperature, we anticipate that there was a possibility of 12.7% deviation in climates between the study area and neighboring climate station.

3. CALCULATIONS AND INPUT DATA

To estimate the daily precipitation from the average monthly data shown in **Figure 2**, we did perform two separate interpolations: 1) rising limb of precipitation; and 2) falling limb of precipitation, which yielded daily

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precipitation data (**Figure 5**). Two separate interpolations were needed because single interpolation was not able to capture the peak rainfall, which occurred in the month of July. The rising and falling limbs of precipitation are shown in **Figure 5**, and interpolated precipitation values (daily) are also shown in the figure. Similarly, daily evapotranspiration was estimated using the average monthly shown in **Figure 4**. The daily evapotranspiration is shown in **Figure 6**.

The model used in this study requires daily input data (precipitation, temperature, evaporation, and evapotranspiration). Evaporation was estimated from evapotranspiration. Previous studies reported that evaporation values vary approximately 120% - 130% of evapotranspiration. In this study, we used daily evaporation values as 130% of the daily evapotranspiration values.

4. RESULTS AND DISCUSSION

The average annual interpolated daily precipitation was slightly less than the observed data. The observed average annual precipitation for the study area was about 1741 mm, while interpolation yielded average annual precipitation of 1478 mm *i.e.*, 81% of the observed values. The average annual evapotranspiration was approximately 1189 mm, while interpolation yielded average annual evapotranspiration of 1147 mm. **Figure 7** shows the soil moisture variations in rainfed and irrigated conditions. In addition, daily precipitation and supplemental irrigation is also shown in the figure. The simulation is shown for starting from Julian Day 1 to Julian Day 150. As shown in the figure, soil moisture was considerably elevated when supplemental irrigation was applied (supplemental irrigation is shown as vertical red bars in **Figure 7**). Soil moisture in the rainfed and irrigated conditions were estimated for two seasons: (Season 1: Julian Day 20 - 119; and Season 2: Julian Day 165 - 264). Compared to the first season, in the second season *i.e.*, beyond Julian Day 165, soil moisture in rainfed and irrigated conditions were comparable because of excess rainfall. The available water storages in ponds were not utilized as supplemental irrigation because the soil moisture was sufficient without supplemental irrigation (data not shown).

At the end of cropping season, the soil moisture content in irrigated condition was almost three times greater than the rainfed soil moisture. Although actual evapotranspiration (ET) was almost two times greater in irrigated condition compared to rainfed condition, the actual yield increased about three times in irrigated condition when compared to the rainfed condition. Addition of 128 mm of supplementary irrigation decreased the green water use by 45% and increased the total water use by 55% compared to rainfed condition. Subsequently the overall water use efficiency showed a nearly 55% increase in irrigated condition. As shown in the **Table 1**, water re-

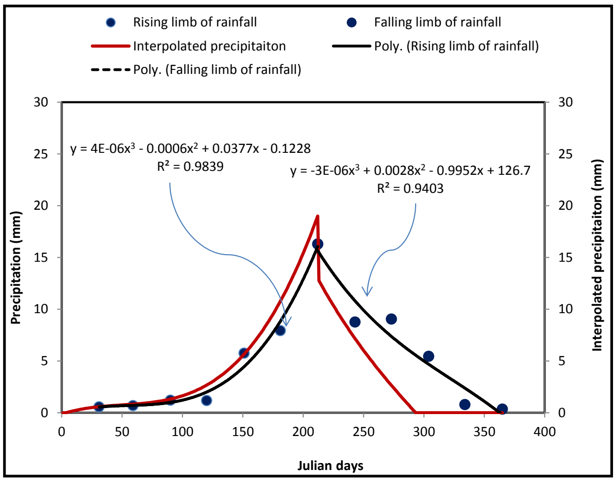

Figure 5. Interpolated daily precipitation.

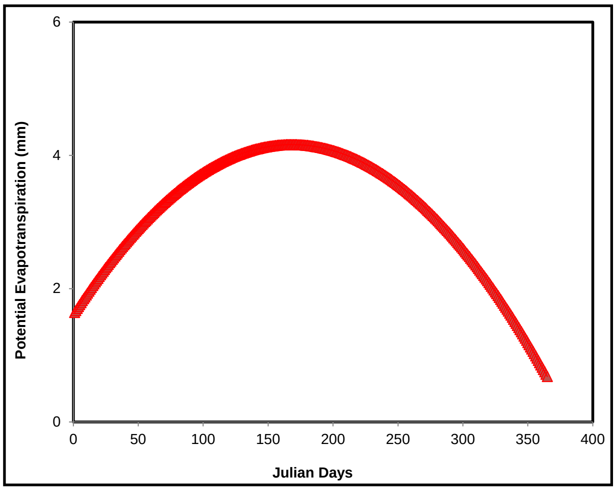

Figure 6. Daily evapotranspiration.

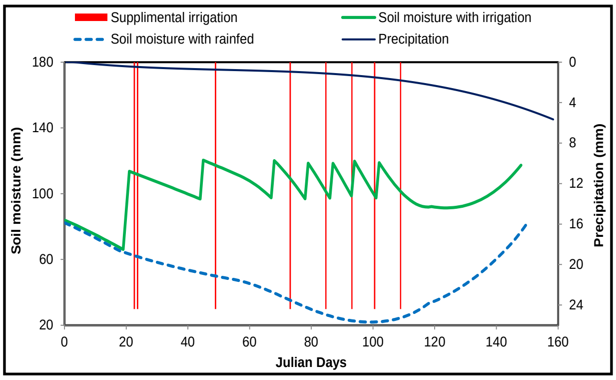

Figure 7. Soil moisture and supplemental irrigation.

charge values (R) of uncultivated land in irrigated condition was 85% of the recharge value of rainfed fed condition. ET value of uncultivated land (*i.e.*, catchment) in irrigated condition was 86% of the rainfed condition. In cultivated land, R and ET values in irrigated condition were higher than the rainfed condition. For example, R

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Table 1. Water balance parameters of catchment area, cultivated land, and crop yields.

Conditions	Parameters					
	AM_e (mm)	ETa (mm)	Y_a/Y_m	Y_a (kg/ha)	TS (mm)	GW (mm)
Irr.	90.2	268.7	1.0	6000	128	73.53
Rain.	33.2	130.5	0.36	2141	0.0	130.48

	Parameters				
	OWUE (kg/m^3)	UA		CA	
		R (m^3/yr)	ET (m^3/yr)	R (m^3/yr)	ET (m^3/yr)
Irr.	2.98	28101	21588	5907	7842
Rain.	1.64	33060	25397	5498	6298

**Note: Irr. = irrigated; rain. = rainfed; AM_e = available moisture at the end of cropping season 1; Y_a = actual crop yield; Y_m = maximum crop yield; TS = total supplemental irrigation applied; GW = green water use; OWUE = overall water use efficiency; R = recharge; ET = Evapotranspiration; UA = Uncultivated land area (catchment area of 5 ha); CA = Catchment area (cultivated land area of 1 ha).

value in rainfed condition was 93% of the irrigated condition, and ET value in rainfed condition was approximately 80% of the irrigated condition. In summary, the results of the study showed that rainwater harvesting approach can be an effective alternative for enhancing agricultural water availability in the rainfed regions.

5. CONCLUSION

A water balance model was used to estimate the impacts of rainwater harvesting approach on enhancing rainfed crop land soil moistures and crop yield for a southwestern district of Bangladesh. The model estimated rainwater storages in water storage tank (designed in the farm land). The model uses algorithms to estimate the water requirement of the crop land as well as water availability in the tanks. This decision making allows model to estimate the supplemental irrigation requirement in the crop land as well as supplemental irrigation availability in the tanks. There sults showed that the rainwater harvesting approach presented here increased crop yield considerably in the studied rainfed region of the Bangladesh. The model requires four major parameters: precipitation, temperature, evaporation, and evapotranspiration. To run the model, daily input data are required. In this study, daily data were estimated from the available monthly data and used to feed the model. We anticipate that the availability of daily observed data will improve the model predictions significantly, therefore, further studies utilizing the daily observed data for predicting supplemental irrigation, soil moisture, and crop yield will be necessary. We suggest future studies utilizing the climate data of multiple locations (rainfed) to enhance the model as well as model predictions.

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