Assessment of Climate Change Impacts on Irrigation Water Requirement and Rice Yield: A Case Study from Ngamoeyeik Irrigation Project in Myanmar

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Summary: This study examines the impacts of climate change on irrigation water requirement (IWR) and yield for rainfed rice and irrigated paddy at Ngamoeyeik Irrigation Project (NIP) in Myanmar. The future climate of the NIP area was projected using the outputs of two General Circulation Models (GCMs) namely ECHAM5 (scenario A2 and A1B) and HadCM3 (scenarios A2 and B2) for future time period of 2020s, 2050s and 2080s. The climate change scenarios were downscaled to basin level by using Statistical DownScaling Model (SDSM). Calibrated and validated AquaCrop v4.0 model was used to forecast the rainfed (May-October) rice yield and irrigation water requirement for irrigated paddy (November-April) under future climate. The analysis shows a decreasing trend in maximum temperature (-0.8 to +0.1°C) for the three scenarios and three time windows considered; however, an increasing trend is observed for minimum temperature (+0.2 to +0.4°C) for all cases. The analysis on precipitation also suggests that rainfall in wet season is expected to vary largely from -29% (2080s; A1B) to +21.9% (2080s; B2) relative to the average rainfall of the baseline period. A higher variation is observed for the rainfall in dry season ranging from -42% for 2080s, B2; and +96% in case of 2020s, A2 scenario. A decreasing trend of irrigation water requirement is observed for irrigated paddy in the study area under the three scenarios indicating that small irrigation schemes are suitable to meet the requirements. An increasing trend in the yield of rainfed paddy was estimated under climate change demonstrating the increased food security in the region.

Keywords: climate change, crop modeling, irrigation water requirements, rainfed paddy yield, Myanmar

1. INTRODUCTION

Agriculture is the lifeline of Myanmar's economy which provides employment to 67% of the working population and contributes to 58% of Myanmar's gross domestic product (GDP) (UNDP 2011). Agricultural production is entirely dependent on the amount of water available in the field and hence, the dryland farmers of Myanmar mainly rely on rainfed farming for their livelihoods and the over dependence on rainfall makes Myanmar economy more vulnerable to climate change (ADB 2009). Rice is the major agricultural crop grown in Myanmar which covers 39.82 % of the total agricultural land area. In order to compensate the insufficient rainwater for irrigation; irrigated rice is being practiced in Myanmar in the new millennia as it provides assurance to the farmers for the summer rice production. A recent increase of 20.3% in the irrigated areas has been observed within a span of 5 years (FAO 2009).

Climate change has become a global threat which has high potential to affect the water and agriculture sectors significantly (IPCC 2007; Molua 2009). In Southeast Asia, temperature is expected to rise by 1.87-3.92˚C and precipitation is anticipated to increase by 1-12% by the end of the century as compared to the current condition (IPCC 2007). With the increased temperature and fluctuating precipitation, it is expected that water availability and crop productivity will decrease significantly in the future (Kang et al. 2009). It is also reported that climate change will have direct and indirect impacts on irrigation water requirement and yield of crops respectively (IFPRI 2009). The change in the yield is mostly expected due to the shift in the growth phase, photosynthesis capacity and increasing in the respiration and an increase in the water requirements. Moreover, various extreme climate events (e.g. floods, cyclones and heat waves) will have additional risk to the agricultural production (Alcamo et al. 2007).

The present study quantifies the change in the irrigation water requirement and rice productivity in an irrigated project area in southern region of Myanmar under different climate change scenarios. The outputs of this research will be highly useful for the farmers, policy makers and reservoir operators of the region to respond the adverse impacts of climate change on water resources and agriculture.

2. MATERIALS AND METHODS

2.1 Study area

The study area lies in the southern region of Myanmar with a catchment area of 414.5 km^2. Ngamoeyeik irrigation project is the largest irrigation project in the lower Myanmar and is located within latitude of 16˚50'-17˚30' N and longitude of 96˚00'-96˚30' E (Figure 1). A substantial hilly region lies in the northern part of the basin with slope ranging from 4.5-9.0% and a flat region exists in the south with average slope 0.3%. In the study area, rice cultivation is generally practiced at a cropping intensity of 200% with rainfed and irrigated conditions. Field preparation for the rainfed rice starts from middle of May and the crops are harvested by early November. In case of irrigated rice, transplantation is done by middle November and the paddy is harvested by middle of April.

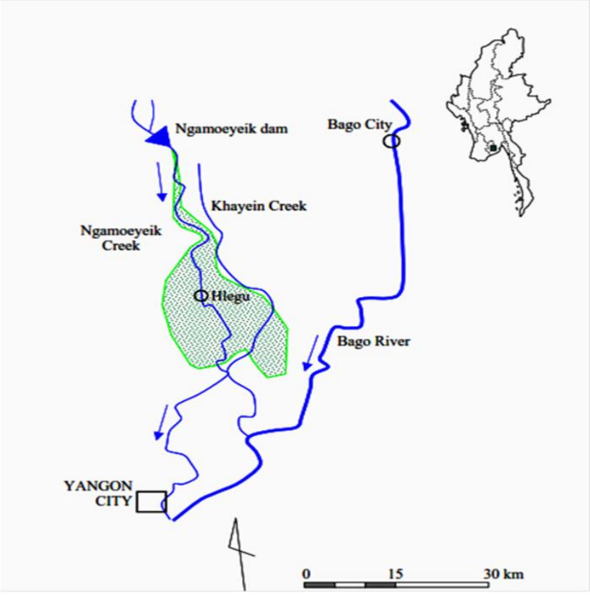

Figure 1. The methodological framework used for the study

2.2 Climate change scenario generation and estimation of rice yield

The outputs of two General Circulation Models (GCMs) ECHAM5 and HadCM3 were used to project the future climate scenarios considering three SRES scenarios A2, A1B and B2. The A2 is considered as highest emission scenario whereas B2 is considered as lowest emission scenario and A1B scenarios is balanced usage of energy resources. These climate change scenarios were downscaled at basin scale by statistical downscaling tool (SDSM) using the daily observed precipitation and temperature dataset obtained from the local meteorological station (Kabar Aye; Yangoon). The results obtained were used as input to the crop model, AquaCrop v 4.0 (Raes et al. 2009a), in order to estimate the rainfed rice yield and IWR for the irrigated paddy. Figure 2 demonstrates the methodological framework applied for this study.

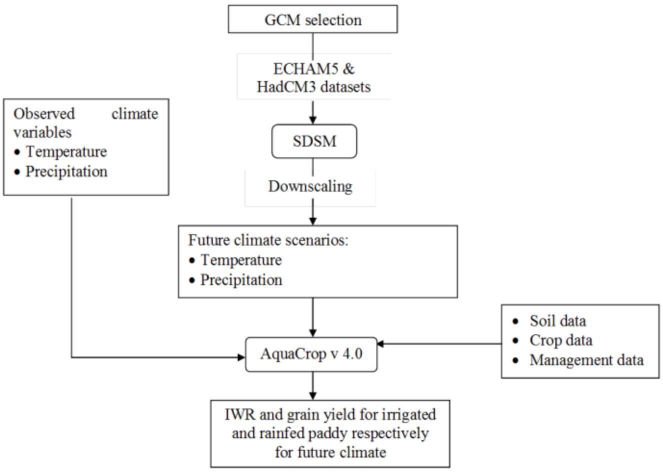

Figure 2. The methodological framework used for the study

3. RESULTS AND DISCUSSION

3.1 Projection of future temperature

The projected maximum temperature shows a decreasing trend whereas, minimum temperature tends to increase for the three scenarios and the three time windows considered (Table 1). The highest decrease in maximum temperature is 0.8˚C for 2020s time window in case of A2 scenario by HadCM3. On the contrary, the largest increase in minimum temperature has been observed in multiple cases with same absolute value of 0.4˚C for A2 scenario in 2020s and 2050s along with 2080s for A1B scenario. The temperatures simulated by HadCM3 showed that although the increase in minimum temperature is not significant, it is however remarkable in the case of maximum temperature (-0.5 to -0.6˚C). It can be noted that in case of A2 and A1B scenarios, the maximum temperature simulated decreases in the near future (2020s) then tends to increase to the current temperature (32.7˚C). For maximum temperature, ECHAM5 shows a variation of -0.2 to 0˚C whereas a higher variability ranging from -0.8 to +0.1˚C is observed for HadCM3 from 2020s to 2080s. Similarly, for minimum temperature observed change for ECHAM5 and HadCM3 ranges from +0.4 to +0.3˚C and -0.4 to +0.5˚C respectively for the corresponding time intervals. The analysis shows that the highest changes in both maximum and minimum temperature are observed in case of 2050s.

Table 1. Future changes in maximum temperature (Tmax) and minimum temperature (Tmin) relative to baseline period (1961–1990) at Ngamoeyeik Irrigation Project, Myanmar

Scenarios		ECHAM5			HadCM3		
		2020s	2050s	2080s	2020s	2050s	2080s
Baseline Tmax (°C)		32.7					
Baseline Tmin (°C)		22.2					
Scenario A2	Tmax (°C)	32.5	32.6	32.7	31.9	32.4	32.8
	Change (°C)	-0.2	-0.1	0	-0.8	-0.3	+0.1
	Tmin (°C)	22.6	22.6	22.5	21.8	22.5	22.7
	Change (°C)	+0.4	+0.4	+0.3	-0.4	+0.3	+0.5
Scenario A1B	Tmax (°C)	32.5	32.6	32.8	-	-	-
	Change (°C)	-0.2	-0.1	+0.1	-	-	-
	Tmin (°C)	22.5	22.5	22.6	-	-	-
	Change (°C)	+0.3	+0.3	+0.4	-	-	-
Scenario B2	Tmax (°C)	-	-	-	32.2	32.3	32.2
	Change (°C)	-	-	-	-0.5	-0.6	-0.5
	Tmin (°C)	-	-	-	22.4	22.4	22.4
	Change (°C)	-	-	-	+0.2	+0.2	+0.2

3.2 Projection of future precipitation

A substantial increase in precipitation is observed in all time windows for A2 and B2 scenarios (Table 2). However, a considerable decline is noted from 2020s to 2080s in case of A1B scenario. A declining trend in precipitation is indicated by ECHAM5 for A1B scenario; similarly by both GCMs for A2 scenario whereas B2 indicates an increasing trend in precipitation magnitude. The highest magnitude of rainfall is observed in case of A2 scenario for 2020s (3273 mm); for the expected abrupt increase in amount of rainfall within a short time, it is suggested to have a proper rainfall forecast throughout the study area to prevent harmful impacts. The increase in total amount of rainfall for A2 and B2 scenarios indicates reduced IWR. However, it is contradictory in case of A1B scenario (discussed later). Interestingly, minor differences can be noted in the projections for A2 scenario in ECHAM5 and HadCM3.

Table 2. Future changes in precipitation (Prcp) relative to baseline period (1961 – 1990) at Ngamoeyeik Irrigation Project, Myanmar

Scenarios		ECHAM5			HadCM3		
		2020s	2050s	2080s	2020s	2050s	2080s
Baseline Prcp (mm)		2700					
Scenario A2	Prcp (mm)	3273	3172	3088	3196	3064	2959
	Change (%)	+21.2	+17.5	+14.4	+18.4	+13.5	+9.6
Scenario A1B	Prcp (mm)	2290	2069	1925	-	-	-
	Change (%)	-15.2	-23.4	-28.7	-	-	-
Scenario B2	Prcp (mm)	-	-	-	3076	3233	3229
	Change (%)	-	-	-	+13.8	+19.7	+19.7

3.3 Projection of future irrigation water requirement (IWR)

The future IWR for the irrigated paddy in case of future time windows and three scenarios was simulated by AquaCrop. Two plausible initial soil moisture conditions combined with two assumed allowable root zone depletion conditions namely at Field Capacity (FC) and 50% of Total Available Water (TAW) were considered for the simulation (Table 3). The nutrient supply is presumed to be at optimum application rate as that of the current situation. The agricultural management practices are also assumed to be unaltered as compared to the present conditions.

Table 3. Future changes in irrigation water requirement relative to baseline period (1961-1990) for irrigated paddy in case of ECHAM5 (A2 and A1B scenarios) and HadCM3 (A2 and B2 scenarios) GCMs

Time period (GCM)	Allowable root zone depletion	Initial condition	Baseline IWR (mm)	Scenario A2 (ECHAM5)		Scenario A2 (HadCM3)		Scenario A1B (ECHAM5)		Scenario B2 (HadCM3)	
				IWR	Change (mm)	IWR	Change (mm)	IWR	Change (mm)	IWR	Change (mm)
2020s	10%	FC	527	486	-41	492	-35	474	-53	498	-29
		TAW 50%	627	577	-50	601	-26	569	-58	582	-45
	25%	FC	486	482	-4	478	-8	433	-53	475	-11
		TAW 50%	607	527	-80	522	-85	547	-60	573	-34
2050s	10%	FC	527	468	-59	460	-67	481	-46	479	-48
		TAW 50%	627	551	-76	546	-81	572	-55	568	-59
	25%	FC	486	431	-55	433	-53	448	-38	435	-51
		TAW 50%	607	524	-83	523	-84	552	-55	545	-62
2080s	10%	FC	527	498	-29	504	-23	491	-36	469	-58
		TAW 50%	627	589	-38	577	-50	577	-50	556	-71
	25%	FC	486	472	-14	480	-6	460	-26	425	-61
		TAW 50%	607	569	-38	602	-5	553	-54	532	-75

TAW: Total available water; FC: Field capacity

Compared to present condition, a decrease in the IWR is observed for the three scenarios at all time windows considered. At FC, lesser IWR is observed as compared to presumed initial condition of TAW at 50% for all allowed root zone depletion conditions in the time windows considered. It is also evident that, with increase in allowable root zone depletion, there is a substantial reduction in IWR. Simulation done for ECHAM5 in case of A2 scenario suggests more irrigation water requirement in terms of depth (mm) for 2080s followed by 2020s and 2050s. A similar trend is observed in terms of magnitude for A1B scenario, where highest IWR is observed in 2080s for all the conditions followed by 2050s and 2020s. However, in the case of B2 scenario, IWR reduces from 2020s to 2080s. The maximum reduction in IWR (83 mm) as compared to present condition is observed for 2050s with 25% allowable root zone depletion and 50% TAW initial condition. Simulation for IWR done with the outputs of HadCM3 (A2 scenario) validates the higher degree of uncertainty in 2080s when compared to that of ECHAM5 projections. IWR simulation results obtained from ECHAM5 for 25% allowable root zone depletion at FC and TAW 50%, suggest a reduction of 14 and 38mm respectively whereas in case of HadCM3 projections IWR stands at 6 and 5 mm for the corresponding conditions.

The trend in forecasted precipitation and minimum temperature can be attributed to the observed decreasing trend in IWR for the three scenarios. It can be clearly observed that for any scenario at a particular time window with projected high precipitation, a lower IWR persists. For instance in case of A2 scenario (ECHAM5), for 2020s, 2050s and 2080s the respective precipitation are 194.8mm, 194.3mm and 146.2mm and the corresponding IWR for 10% allowable root zone depletion and initial condition at FC are 486mm, 468mm and 498mm. Similar results were shown by Gerten et al. (2011) and Olesen et al. (2007) which indicates reduction in IWR by 4 to 82% by the end of 21st century varying on crop and location. The projected decrease in IWR for the future climate scenarios indicates the need of better management plan for the diversion of the reservoir water to other sectors during the dry months.

3.4 Projection of future rainfed paddy yield

An increase in the rainfed paddy yield is observed for the three scenarios and the three time windows considered. An explicit increasing trend is observed from 2020s to 2080s for A2 scenario in case of both GCMs. The projected yield for ECHAM5 shows a change of +40.3 % for A2 scenario whereas for HadCM3 +35.9% change is observed for the corresponding scenario. It can also be noted that the uncertainty is higher in magnitude for the late part of century relative to the early and mid part. In addition, a fluctuating trend is observed in case of A1B and a decreasing trend is observed in B2 scenario (Table 4). Maximum variation is observed for A2 scenario ranging from +21.1 to +40.3% from 2020s to 2080s. It can be observed that for rainfed paddy, the trend of yield is irrespective of the trend of maximum temperature and precipitation. However, the increase in yield follows the same trend as that of minimum temperature. Modeled higher yields in case of A2 followed by A1B and B2 scenarios may also be induced due to the accumulated CO_2 concentration in the atmosphere. Higher CO_2 level causes increase in minimum temperature which combined together due to heat-induced spikelet aggravated growth and increased biomass and subsequent grain yield

(Wassmann, 2007; Krishnan et al. 2007). Similar increase in yield was also shown by Alexandrov et al. (2002) and Laux et al. (2010) for Austria and Cameroon respectively. In case of Southeast Asia, Northeast Thailand and winter-spring cropping pattern of Vietnam are supposed to be benefitted by climate change as modeling study suggests increased rice yield (SeaStart 2006).

Table 4 Future changes in rainfed rice yield relative to baseline period (1961-1990) for ECHAM5 (A2 and A1B scenarios) and HadCM3 (A2 and B2 scenarios) GCMs

Scenarios	Baseline yield (t/ha)	2020s		2050s		2080s	
		Yield (t/ha)	Changes (%)	Yield (t/ha)	Changes (%)	Yield (t/ha)	Changes (%)
A2_ECHAM5	2.965	3.590	+21.1	3.932	+32.6	4.159	+40.3
A2_HadCM3		3.612	+21.8	3.991	+34.6	4.029	+35.9
A1B_ECHAM5		3.573	+20.5	3.783	+27.6	3.745	+26.3
B2_ECHAM5		3.571	+20.4	3.465	+16.9	3.455	+16.5

The decreasing trend of IWR for summer paddy is observed for all three time windows. Since the paddy is already in irrigated condition and the maximum yield is attained, the paddy doesn't respond to further increase in rainfall during summer season. Therefore very little increase or no further increase in the yield of summer paddy can be expected.

The projected increase in yield of rainfed paddy due to climate change is an indication of increased food security in the study area. However, evaluation of adaptation strategies can be performed in order to enhance the yield up to its potential level. Although it is expected to have an increased paddy yield under climate change but severe risk exists due to the increased precipitation as high magnitude of precipitation can also cause unexpected floods in the region if proper management practices are not being taken.

4. CONCLUSION

This study is divided into three parts: first is forecasting the future climate variables, then using the projected climate variables to forecast the future irrigation water requirements for irrigated paddy and thirdly, assessing the impacts on future rainfed rice productivity. SDSM has been used to downscale the coarse resolution of climate variables from the GCMs (HadCM3 and ECHAM5). A2, A1B and B2 scenarios were used to assess the IWR and rainfed rice yield. SDSM was calibrated for the period of 1961-90 and validated for 1991-2000; performance statistics shows modeled outputs were in good agreement with observed ones. A decreasing trend in maximum temperature is observed for A2 scenario for the projections by ECHAM5 whereas a contradictory increase is observed for the projection by HadCM3. A fluctuation in forecasted temperature is noted for A1B and B2 scenarios for the three time windows considered (2020s, 2050s and 2080s). In case of minimum temperature, an increasing trend is observed for A2 and A1B scenarios however, an increase of +2˚C is expected to prevail constantly for B2 scenario for the three time windows. The future precipitation is expected to increase in magnitude by 14.4 and 19.7%for A2 and B2 scenarios by 2080s compared to present. However, a decreasing trend is observed in case of A1B scenario which is expected to reduce more in future time intervals (-28.7% in 2080s compared to present).

AquaCrop model was used for the study area and was calibrated and validated based on the field experimental data acquired for the agricultural research center. Projection of future IWR was done for the irrigated paddy based on the downscaled climate data. Due to the forecasted increase in the winter precipitation, the IWR is expected to be lowered by the end of the century for A2 and B2 scenarios. However, even the precipitation is forecasted to decrease, in the case of A1B scenario, the IWR is expected to be reduced due to shift in temperature pattern. Results obtained for rainfed rice simulated by AquaCrop suggests an increasing yield in the region for A2 scenario. A fluctuating increased trend is observed for the A1B scenario and reducing trend is noted for B2 scenario (+20.4% in 2020s to +16.5% in 2080s). It can also be inferred that due to the reduced IWR in the future the reservoir operation needs to be evaluated to divert the water to other sectors for better water resources management. The results can be further utilized to investigate the effects of different cropping patterns with varying crop calendars on the water demand.

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