



Assessing the impacts of climate change on irrigation diversion water requirement in the Philippines

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Abstract

This study assessed the impacts of climate change on diversion water requirements for irrigation system planning and development in the Philippines. Representative sites with high potential for irrigation development were selected from each of the four climatic types in the country. Cropping calendars were developed based on evapotranspiration and rainfall patterns. The CROPWAT program was used to determine the net irrigation requirement, from which the irrigation diversion requirements were derived based on estimated irrigation efficiencies. Recently published climate projections using the representative concentration pathways were used as climate change scenarios. Results of this study showed that the CROPWAT estimates of evapotranspiration were satisfactorily calibrated and validated using the eddy covariance methods. Climate change could lead to a significant increase in diversion water requirement. The increase in diversion water requirement was projected to reach + 43% during dry years, + 32% during normal years, and + 42% during wet years. A favorable reduction in diversion water requirement due to timely occurrence of rainfall was however observed at the site with distinct wet and dry season during dry years (up to - 7%), normal years (up to - 11%), and wet years (up to - 12%). The cropping patterns varied within and across climate types. The projected estimates of diversion water requirements generated in this study could be used for irrigation system planning and development particularly for assessing water storage requirements and design irrigable areas. Results could also be used as part of planning and design criteria for dams and reservoirs and thereby contribute to climate proofing of irrigation systems. The application of methods developed in this study for estimating diversion water requirements with the incorporation of climate change may be extended to other parts of the country and in other parts of the world for a more climate-resilient water resources planning.

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1 Introduction

As temperature continues to rise in agricultural areas due to climate change, crop water requirements and irrigation water requirements at various levels are expected to increase due to increase in evapotranspiration. Consequently, more water will be needed to produce food. This is compounded by the fact that rainfall is projected to decline towards the end of the century thereby reducing water resources for food production (Jose and Cruz 1999; Philippine Atmospheric Geophysical and Astronomical Services Administration 2018). As population continues to increase, it is imperative to grow more food strategically especially the staples like rice. The Philippines' population has exponentially grown to 101 million in 2015 which is higher by 8.64 million compared to the population in 2010 and higher by 24.47 million relative to the year 2000 (National Economic and Development Authority 2017). By 2045, the country's population is projected to reach 142 million. This growth has posed pressure on the agriculture sector to produce more to meet the growing demands on food. Rice self-sufficiency target has never been achieved despite the government's efforts due to numerous factors. The most important factors include extreme climate variability and climate change that have brought huge economic losses in the country's agriculture sector.

The Philippines is ranked 3rd in terms of the level of disaster risks based on the World Risk Report (Heintze et al. 2018). Huge economic losses due to climate change and disasters have been accounted for by the Department of Agriculture to reach PHP163.6 billion in agriculture from 2011 to 2015. A single event of prolonged drought due to El Niño in 2010 resulted in 12 billion pesos (US\$235million, 1Php = US\$54) of economic loss in agriculture which adversely affected the livelihood of many smallholder farmers. The current trend shows that severe drought occurs in the country every 4 to 5 years, which would mean more potential damages to crop production. A study on rice production by Lansigan et al. (2000) proved that 65, 81, and 52% declines in rice yield were experienced in the Philippines due to the strong El Niño events in 1973, 1983, and 1990, respectively. Furthermore, trend analyses of rice yield showed declines for every 1 °C increase in seasonal mean temperature by 15% from 1979 to 2003 (Peng et al. 2004) and by 13.7% from 1970 to 2005 in the rainfed areas in the country (Roberts et al. 2009).

The water availability for food production has been proven to be greatly affected by climate change (Jose et al. 1996; Rao et al. 2011). Crop water use is found to substantially increase due to climate change in other countries (Parekh et al. 2007; Lee and Huang 2014; Chowdhury et al. 2016). Rice production may decline significantly due to the water supply deficit caused by an increment in crop water use (Boonwichai et al. 2018). The climate projections show that temperature in the Philippines will continue to rise towards the end of the century and that seasonal rainfall would vary largely which could potentially make drier dry seasons and wetter wet seasons (Philippine Atmospheric Geophysical and Astronomical Services Administration 2018). In these cases, interventions to reduce the adverse impacts of climate changes are necessary. Water resources development plans should consider the projected climate changes to ensure climate-proofed irrigation systems. Quantifying irrigation requirements amidst climate changes could serve as basis for the proper assessment of the need and suitability for water storage. The government recognized this need in its medium-term plan.

Determination of irrigation water requirements is necessary for irrigation water master plans and designs. There is a need for site-specific design criteria. A classic example is the water duty of 1.5 l/s/ha, which is used universally by the National Irrigation Administration (NIA) for irrigation system planning regardless of geographic location, soil type, and climate (Ella 2016). This study intends to demonstrate how to quantify this variable as design criteria for irrigation systems. The Food and Agriculture Organization (1997) determines irrigation water requirements by taking into account the climate and cropping pattern. The FAO developed a computer-based program that was specially created to quantify crop water requirement called CROPWAT. This tool has been widely used in estimating water requirements of various crops (Savva and Frenken 2002; Tibebe and Zemadim 2015; Surendran et al. 2015; Hamidon et al. 2015; Rajendran et al. 2017; Ewaid et al. 2019). There are also many computer-based programs for computing irrigation water requirements other than the CROPWAT. The EPIC (Erosion-Productivity Impact Calculator) which does not consider percolation and infiltration from paddy fields was used by Wriedt et al. (2009) in estimating spatial irrigation water requirement in Europe. They assumed constant rice paddy irrigation water requirements on top of the EPIC calculation of water requirements for other crops. The EPIC is a crop growth model that uses soil sub-equations for crop growth, nutrient balance, climate, and soil hydrology (Williams 1995). The Global Irrigation Model has been used to quantify the global irrigation water requirements in 0.5° by 0.5° raster grid cells (Döll and Siebert 2001; Döll 2002). Alarmingly, they found that 67% of the irrigated area at the global scale would suffer from increased irrigation water requirements due to climate change. Irrigation diversion requirement is the irrigation water requirement plus the losses in conveying water from the source to the irrigation service areas.

The CROPWAT was developed by the Food and Agriculture Organization (FAO) primarily to compute crop water use and net irrigation schemes (Smith 1992). It has been used to evaluate deficit irrigation (Food and Agriculture Organization 2000) and widely applied for estimating crop water requirements and irrigation requirements of various crops (Tibebe and Zemadim 2015; Surendran et al. 2015; Ewaid et al. 2019). Various studies assessed the impacts of climate change that are limited only on crop and irrigation water requirements (Doria et al. 2006; Shrestha et al. 2014; Hamidon et al. 2015; Rajendran et al. 2017; Rotich and Mulungu 2017). None of these studies extended the tool's application in estimating diversion water requirement, which is important in developing dynamic cropping calendars for irrigation systems especially with the effect of climate change. Crop water requirements vary widely across countries due to the differences in climate systems, and this thereby suggests the need for the same study in the country. This study extends the assessment to the estimation of irrigation diversion water requirements based on crop water use estimation incorporating the effect of climate change. Knowledge of projected diversion water requirements can then be used to estimate potential irrigable areas based on dependable water supply for irrigation development projects. Alejo and Ella (2019) used CROPWAT to estimate irrigation diversion water requirements as required to investigate the effect of climate change on irrigation planning and development in the Philippines. However, they focused on the impact of climate change on potential irrigable areas and their estimation of diversion water requirement was only limited to their baseline year 2013 for climate type III. They assumed that the diversion water requirement across climate change scenarios was the same, which reflects the current inadequate practice. This study will show how diversion water requirement varies with climate change, highlighting the need to use updated values of the parameter in irrigation systems. The country's climate is categorized into four types, which vary according to rainfall distribution.

This study aimed to quantify the impacts of climate change on diversion water requirements in selected proposed irrigation systems under the four climate types in the Philippines using CROPWAT.

2 Methods

2.1 The study sites

The study sites were selected in the regions with a high potential for irrigation development as identified in the Philippine Development Plan 2017–2022. The selected areas were based on the list of pipelined projects for proposed dams in the Philippines. There are no wide variations in topography in the potential or design service areas because they are flat to gently sloping since these are intended for irrigation development for lowland rice production. Sites were selected such that the four climate types in the Philippines had one site each. The study area for the type I climate was selected from Central Luzon, type II from the Bicol Region, type III from the Cagayan Valley Region, and type IV from SOCCSKSARGEN. The Philippine climate is characterized based on rainfall distribution as climate type I, II, III, and IV. According to (PAGASA 2014), climate type I has two prominent seasons, dry (November to April) and wet (rest of the year) from June to September. Climate type II does not have a dry season with the highest rain amounts taking place from December to February and the lowest monthly rainfall in December or February or from March to May. Climate type III is characterized by a dry season that only lasts from 1 to 3 months (either December to February or March to May) with no distinct maximum rain period. Climate type IV has uniformly distributed rainfall throughout the year and does not have a dry season. The selected sites have significant potential crop production areas. The five selected sites are located in four climate types in the Philippines. The Maringalo site is located under climate type I, Daet under climate type II, Maasin and Abuan under climate type III, and Kabulnan2 under climate type IV as shown in Fig. 1.

2.2 CROPWAT overview

CROPWAT was used to determine the irrigation supply scheme for a rice-rice cropping pattern. It is a computer-based tool developed by the Food and Agriculture Organization (FAO) for quantifying crop water requirements and irrigation scheme supply (Food and Agriculture Organization 2005). It yields the irrigation water requirement at the field level. To generate these, it needs primary data inputs that include climate (temperature, relative humidity, wind speed, and sunshine hours), rainfall, crop data, soil, and cropping pattern. The general equation of CROPWAT in estimating the net irrigation requirement (IR_n) is as follows.

$$IR_n = ET_c - (P_e + G_e + Wb) + LR$$

where ET_c is the crop evapotranspiration, P_e is the effective rainfall, G_e is the groundwater contribution from the water table, Wb is the water stored in the soil profile at the beginning of each period, and LR is the leaching requirement.

The climate module can compute the solar radiation and evapotranspiration in daily, decadal, and monthly time scales. Inputs such as the planting activities are given in days,

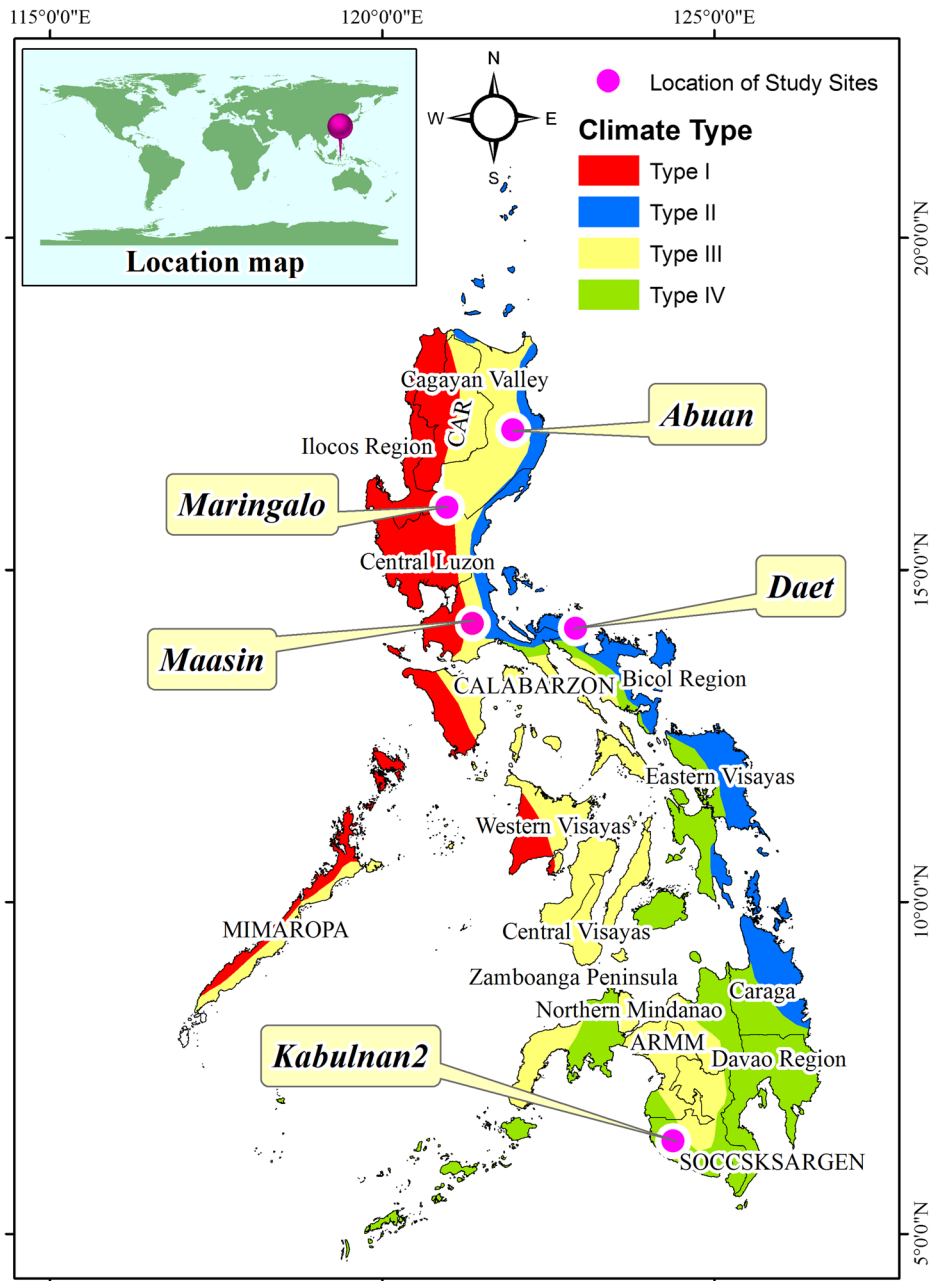


Fig. 1 Locations of the study sites across climate types in the Philippines

i.e., transplanting activities commenced 21 days after sowing, but the time scale for the outputs is aggregated by months. The CROPWAT uses the Penman-Monteith equation in estimating potential evapotranspiration and considers the crop coefficients to generate the evapotranspiration for each time scale. The Penman-Monteith is internationally considered the most

comprehensive and standard approach that combines mass transfer and energy principles and takes into account numerous climatological parameters like temperature, relative humidity, solar radiation, sunshine duration, wind, and atmospheric pressure for evapotranspiration estimation. The Penman-Monteith has been used as actual evapotranspiration for validating satellite-derived evapotranspiration (Stancalie et al. 2010; Ghaderi et al. 2020).

The effective rainfall can be generated by CROPWAT in 5 methods namely fixed percentage, dependable rainfall by FAO/AGLW formula, empirical formula, USDA Soil Conservation Service, and rainfall not considered in irrigation calculations (effective rainfall =0). The USDA Soil Conservation Service method was used in this study. Further details on the CROPWAT equations were explained by Savva and Frenken (2002). The groundwater contribution from the water table and the leaching requirements were assumed negligible.

2.2.1 CROPWAT calibration and validation

An ET_c derived from an eddy covariance (EC) instrument in a rice field planted in and by the International Rice Research Institute, Los Baños, Laguna (latitude: 14° 11' N, longitude: 121° 15', elevation: 21 m) during the dry season of 2015–2016 was used to assess the CROPWAT performance on estimating crop water requirements. The CROPWAT rice parameters particularly the crop coefficient, K_c , were calibrated to fit its generated evapotranspiration to the eddy covariance-based evapotranspiration. The CROPWAT program estimates evapotranspiration as the product of potential evapotranspiration, ET_o , and crop coefficient. One of the most established measurement techniques to estimate evapotranspiration is the eddy covariance (EC) method (Aubinet et al. 2012). Latent evapotranspiration heat (LE) is estimated by EC methods based on the covariance between the vertical wind velocity and the specific humidity. Performance indices such as the coefficient of determination (R^2), RMSE (root mean square error)–observations standard deviation ratio (RSR), Nash-Sutcliffe (NSE), and percent bias (PBIAS) were used to assess the CROPWAT ability to estimate evapotranspiration. Based on Moriasi et al. (2007), a model is performing well with R^2 greater than 0.50, RSR less than 0.7, NSE greater than 0.5, and PBIAS between $\pm 25\%$.

2.3 Development of cropping pattern

For each study area, the evapotranspiration and rainfall curves were developed for the historical and projected climate scenarios. The point where evapotranspiration and the curves of rainfall intersect was set as the start of cropping seasons. The start of cropping seasons produced from this phase was used as input in estimating the requirements for irrigation water.

2.4 Estimation of irrigation water requirements and diversion water requirement

Net irrigation requirement generated by CROPWAT represents the field irrigation requirement that takes into account the crop water requirements and effective rainfall. On the other hand, the diversion water requirement estimated in this study represents the system level irrigation requirement that includes field irrigation requirement, farm application losses, and conveyance losses. In CROPWAT, the data input needed in the estimation of irrigation water requirements at various levels include the baseline and projected rainfall, climate, soil, crop management, and crop coefficients. The default crop and crop coefficients for rice were chosen. A 130-day rice variety was followed for virtual planting based on FAO default settings in CROPWAT.

The default rooting depth ranged from 100 cm during the initial growth stage up to a maximum of 300 cm starting from the mid-season stage until the late-season stage. Planting was set to the optimum planting periods in the study areas, both for the dry and wet seasons, based on evapotranspiration and effective rainfall from CROPWAT. A 2-month fallow period after the dry cropping season and a mid-season fallow period of 1 month after wet season were set. The transplanting activities commenced 21 days after sowing. Evapotranspiration is determined by CROPWAT considering the climate of each site and effective rainfall was computed by selecting the USDA soil conservation service method. The soil in CROPWAT is categorized as light, medium, and heavy. Based on soil maps, the medium soil for Maringalo, Daet, Abuan, and Kabulan2 and heavy soil for Maasin were selected. CROPWAT refers to sand for light soils, loam for medium soils, and clay for heavy soils. The net irrigation requirement computed by CROPWAT does not include irrigation application losses. The diversion water requirement was calculated based on recommended values of irrigation efficiencies for irrigation system planning. More specifically, an application efficiency of 70% and conveyance efficiency of 80% were used in this study. The diversion water requirement was manually computed by dividing the net irrigation requirement by application efficiency to obtain the farm water requirement which was then divided by a conveyance efficiency to estimate the diversion water requirement.

$$FWR = \frac{FIR \text{ (from CROPWAT)}}{E_a}$$

$$DWR = \frac{FWR}{E_c}$$

where FIR is the field irrigation requirement in li/sec/ha estimated from CROPWAT, FWR is the farm water requirement, and DWR is the diversion water requirement. In this study, the application efficiency and conveyance efficiency were assumed to be 70% and 80%, respectively. These are the widely accepted levels of irrigation efficiency used in irrigation system planning.

2.5 Assessment of impacts of climate change on diversion water requirement

The impacts of climate change on diversion water requirements were estimated by creating weather inputs based on the projected changes in rainfall and temperature. Percent changes in diversion water requirements were computed to quantify the impacts of the projected climate scenarios. These scenarios were based on the climate projections recently published by the Department of Science and Technology - Philippine Atmospheric, Geophysical and Astronomical Services Administration (DOST-PAGASA). They used the new Representative Concentration Pathways (RCPs) from the IPCC, which were downscaled into a resolution of 25 by 25 km². The new RCPs consider population growth, economic development, and technology associated with any RCP. The Philippines' new climate projections are based on 2 greenhouse gas concentration pathways namely RCP 4.5 (moderate level) and RCP 8.5 (high level) for 2-time frames, mid-twenty-first century (2036–2065), and end of the twenty-first century (2070–2099). These scenarios were primarily chosen for the study since according to DOST-PAGASA, these are the scenarios that will likely happen in the future. The medium range was based on historical emissions and the high range was developed for impacts and

adaptation point of view. The downscaling using the regional climate models and the validations were done by PAGASA. They downscaled the Global Climate Models (GCM) by using 4 Regional Climate Models namely the Conformal Cubic Atmospheric Model (CCAM), the Providing Regional Climates for Impacts Studies (PRECIS), the RegCM4, and the HadGEM3-RA, which are further detailed in Philippine Atmospheric Geophysical and Astronomical Services Administration (2018). The resolution is relatively coarse; however, based on Valencia et al. (2015) and Plummer et al. (2003), this is already eligible for the study. The World Meteorological Organization suggested that the radius of influence of rain gauges is 25 km, which qualifies the rainfall input to the model. Moreover, Valencia et al. (2015) reported from their study that rainfall has a radius of influence from 6 km for daily scales to 15 km for annual data.

Values of rainfall and temperatures for both time periods across each scenario were adjusted based on the percentile changes in rainfall and increases in temperature in the climate projections. All the adjustments were relative to the local baseline data in each area and were inputted in CROPWAT. These were made to account for changes in climate in the study areas. Mean values for each RCP climate projections however are provided for the normal (median), driest (lower bound), and wettest years (highest bound). These ranges of climate projections were utilized for projecting irrigation diversion requirement for each bound. The uncertainties in the climatic projections were carried over in the projections of irrigation diversion requirements.

The climate projections were given in quarterly averages. These are summarized in annual mean values presented in Table 1. The projections showed increased annual rainfall amounts during wet years that are intensified towards the end of the twenty-first century and as RCP rises. On the contrary, decreased annual rainfall is expected during dry years and sometimes in the normal years. Based on the percent annual changes in rainfall, the Abuan site under climate type III seemed to have the least changes during dry and normal years all of which occurred in the late twenty-first century under RCP8.5. However, the changes in annual rainfall seemed to have almost the same upper level in all sites, which all occur in the late twenty-first century under RCP8.5. There could be an additional annual increase in rainfall by as much as + 28% during wet years and a reduction by as much as - 29%. The projections clearly say that climate will become warmer in all the study areas towards the end of the century that could reach a record increase as much as + 4.1 °C which translates to an average of 32 °C. This highest value could be felt in the Kabulnan2 site. The annual mean temperature in the Maringalo site under climate type I might increase from + 1.0 °C (28.6 °C) to + 4.1 °C (31.7 °C). Climate type II which is represented by the Daet site can become hotter by + 1 °C (28.6 °C) to + 3.9 °C (31.5 °C). Under climate type III, the Maasin site might experience a temperature surge that could range from + 1 °C (28.5 °C) to + 4 °C (31.1 °C) while the Abuan site might have an increase of + 0.9 °C (28 °C) to 4 °C (31.1 °C).

3 Results and discussion

3.1 Results of calibration and validation of CROPWAT

The final value of calibrated rice crop coefficient was 0.50 for the initial growth stage, 1.05 for the mid-season growth stage, and 0.70 at the end of the growing season. The CROPWAT program satisfactorily estimated ET_c based on its performance statistic with an R^2 value of 0.69, RSR value of 0.62, NSE value of 0.61, and a PBIAS value of 1.49% (Fig. 2). The trend

Table 1 The percent change in annual rainfall and increase in temperature in all sites

Century	RCP	Percent change in annual rainfall, mm			Increase in temperature, °C			
		Dry years	Normal years	Wet years	Dry years	Normal years	Wet years	
Maringalo (climate type I)								
	Baseline		2056			27.6		
	Mid-21st	RCP 4.5	- 13%	- 9%	10%	1.0	1.2	1.8
		RCP 8.5	- 14%	- 3%	15%	1.3	1.7	2.3
	Late 21st	RCP 4.5	- 15%	- 6%	8%	1.3	1.6	2.5
		RCP 8.5	- 22%	- 10%	19%	2.6	3.2	4.1
Daet (climate type II)								
	Baseline		3466			27.6		
	Mid-21st	RCP 4.5	- 9%	0%	16%	1.0	1.2	1.7
		RCP 8.5	- 8%	6%	19%	1.3	1.6	2.2
	Late 21st	RCP 4.5	- 13%	2%	18%	1.3	1.5	2.5
		RCP 8.5	- 19%	4%	26%	2.4	3.0	3.9
Maasin (climate type III)								
	Baseline		1986			27.5		
	Mid-21st	RCP 4.5	- 12%	- 5%	10%	1.0	1.2	1.8
		RCP 8.5	- 13%	- 2%	14%	1.3	1.6	2.2
	Late 21st	RCP 4.5	- 18%	- 7%	13%	1.3	1.6	2.5
		RCP 8.5	- 29%	- 11%	19%	2.5	3.0	4.0
Abuan (climate type III)								
	Baseline		2394			27.1		
	Mid-21st	RCP 4.5	- 8%	1%	17%	0.9	1.2	1.7
		RCP 8.5	- 8%	8%	22%	1.2	1.6	2.2
	Late 21st	RCP 4.5	- 9%	2%	18%	1.2	1.5	2.5
		RCP 8.5	- 12%	5%	28%	2.4	3.0	4.0
Kabulnan2 (climate type IV)								
	Baseline		2119			27.9		
	Mid-21st	RCP 4.5	- 23%	- 3%	14%	1.0	1.1	1.8
		RCP 8.5	- 17%	- 1%	19%	1.3	1.6	2.2
	Late 21st	RCP 4.5	- 18%	- 3%	19%	1.3	1.5	2.5
		RCP 8.5	- 25%	- 8%	27%	2.6	3.2	4.1

line between the CROPWAT-derived and EC-derived evapotranspiration corresponds well to the line of best fit. A study showed that ET_c from the EC method also corresponds well with the ET_c measured by lysimeters (Moorhead et al. 2019). This means the CROPWAT program can be used to estimate crop water requirements in place of EC instruments and the lysimeters method for ET_c measurements.

3.2 Crop seasonal boundaries at the selected sites

The curves for monthly effective rainfall and potential evapotranspiration given by CROPWAT are presented in Fig. 3. The length or duration of the historical time series varies per site depending on the availability of local baseline data. Based on the curves, the Maringalo site under climate type I could start the cropping for the dry and wet season in November and June, respectively. For climate type II in Daet River, the dry season was chosen to start in December just in time after the wet cropping season which starts in June. The effective rainfall under climate type II was observed to be sufficient for

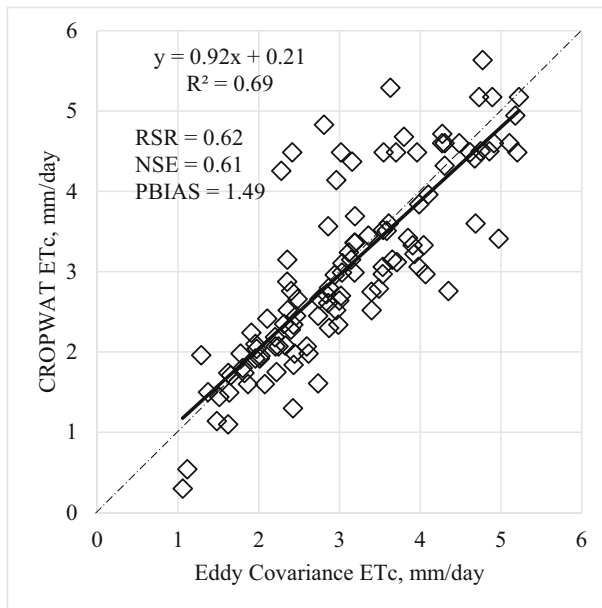


Fig. 2 Eddy covariance measured ETc vs CROPWAT-derived ETc

evapotranspiration almost all year round. This is the climate type where reservoirs are most suitable to act as flood control more than as irrigation storage. In climate type III, the wet season starts in June followed by the dry season that starts in December in the Maasin site. Meanwhile, the Abuan site could start the wet season in July followed by a dry season in January. The climate type IV site in which the Kabulnan2 is located had the earliest initiation for the wet season in May and the dry season in November.

3.3 Cropping calendar development

Based on the commencement months for rice planting, the cropping calendar for each site was developed as shown in Fig. 4. The area covered for each farm activity was subdivided into 3 percentages, 34, 64, and 100% of the service areas. A lag time of 3 weeks for farm activities was assumed to accommodate more areas to irrigate. The Kabulnan2, which has the largest target service area indicated by the NIA, was subdivided into 5% area covered, which translates to 20% per activity. Because of the variability in rainfall and climate, the cropping calendar for each climate type in the Philippines varied relatively except for climate type I and II. The Maringalo site under climate type I, the Daet Site under climate type II, and Maasin under climate type III can all commence land soaking for the dry season in December and would harvest in April. The wet seasons in these 3 sites could start 2 months from June to October. The Abuan site under climate type III should start in January for the dry season until May for harvest while the wet season begins in July until harvest by November. The dry season for Kabulnan2 under climate type IV can start in November similar to the Maasin site. However, because of the larger potential irrigable area that can be supplied by the larger Kabulnan2 River, the dry cropping season at this site ends longer in April. Its wet season starts in May and would harvest in October. This part of the study revealed that even with the same

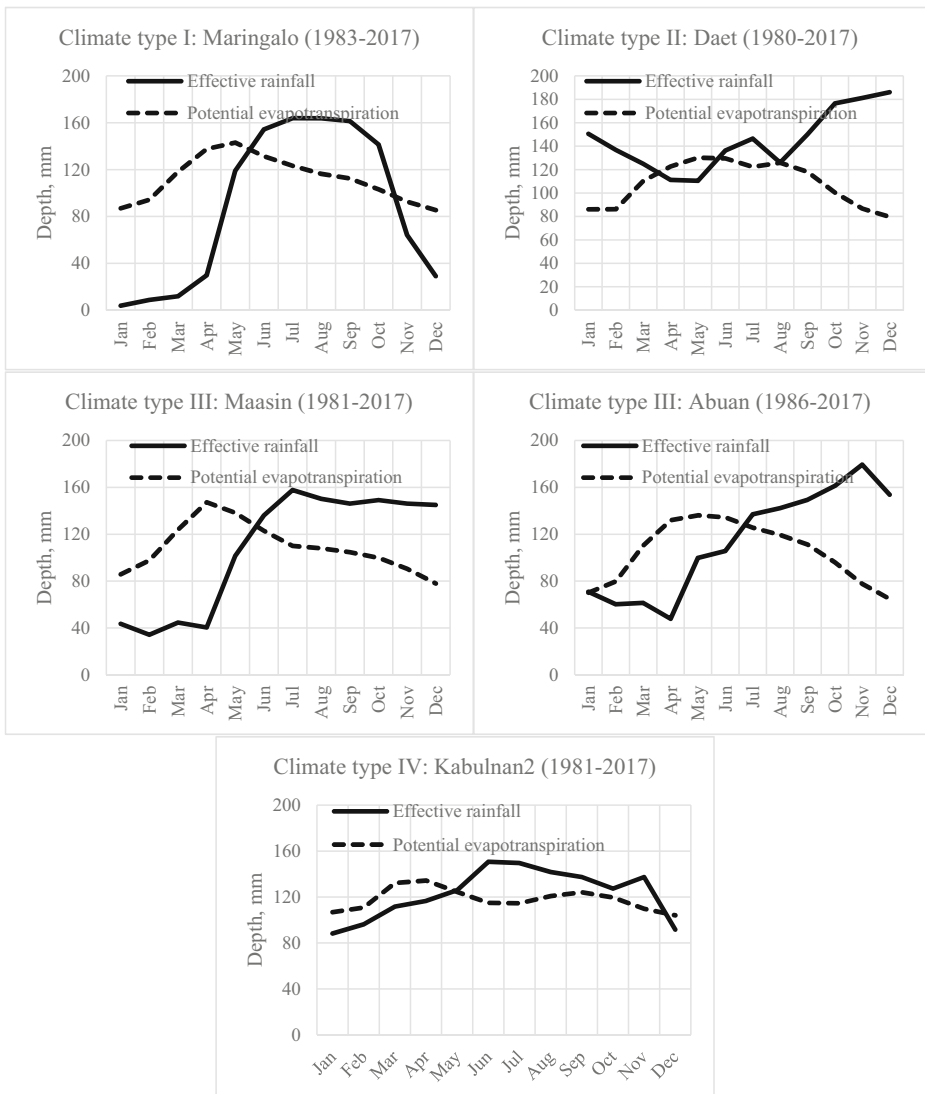


Fig. 3 Monthly effective rainfall and potential evapotranspiration in all the sites

climate types, the cropping calendar could vary like the case of Maasin and Abuan sites. On the other hand, it also demonstrated that even if climate type varies, a similar cropping calendar could be possible as in the case of Maringalo and Daet under climate type I and II, respectively. This emphasizes the importance of long-term and sustained weather monitoring especially in large irrigation systems to retrofit their cropping calendar and optimize water resources especially the rainfall. Alejo (2018) underlines the need for additional agrometeorological stations considering the variable factors in archipelagic countries such as the Philippines. This could also provide for necessary assessment studies for irrigation system development plans in the country.

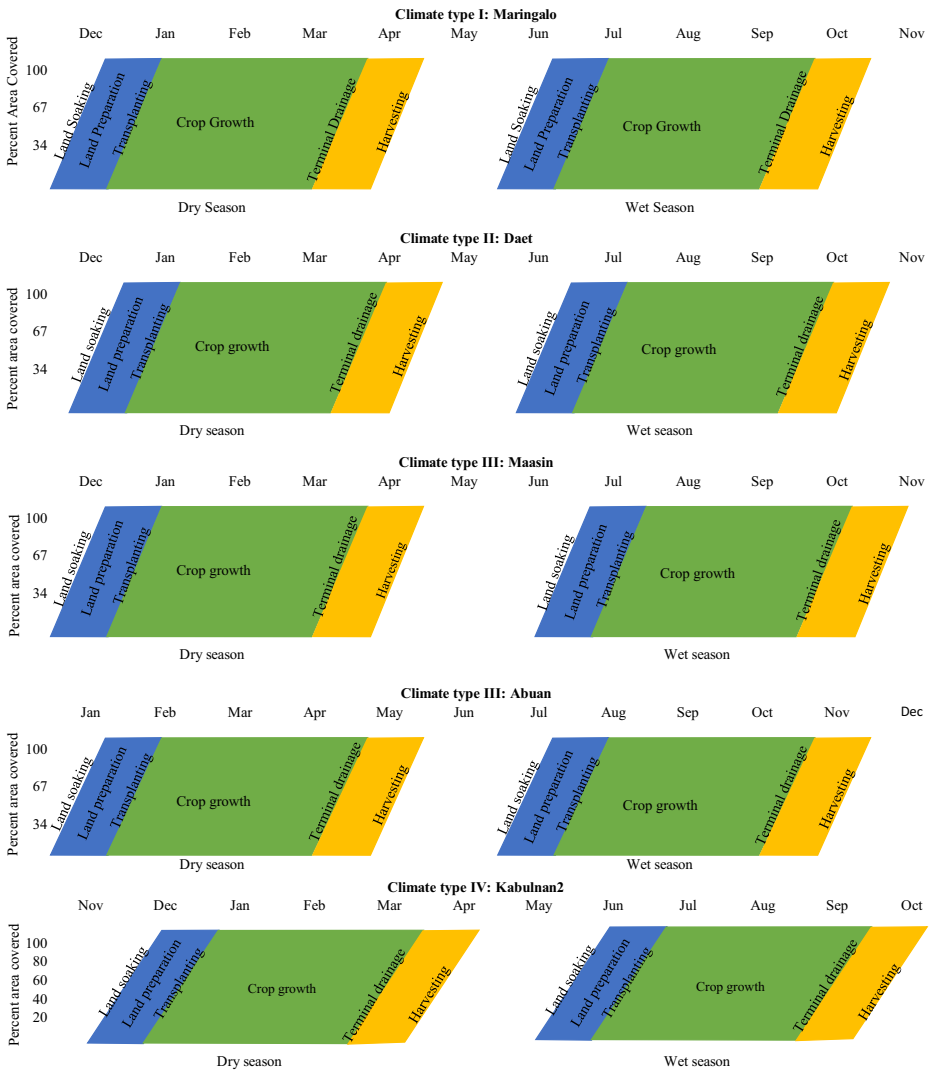


Fig. 4 Cropping calendar for each of the sites based on corresponding rainfall-potential evapotranspiration curve

3.4 Impact of climate change on irrigation diversion water requirement

Based on the CROPWAT computation of net irrigation schemes, the diversion water requirements for each study site were calculated and are shown in Table 2. The diversion water requirement (DWR) in the baseline period across the scenarios did not vary much, which ranged from 1.29 to 1.43 l/s/ha. The highest DWR was observed in Daet and the lowest in Kabulnan2 since the percent covered area per activity was lesser compared to those of the rest of the study sites. Projections showed that due to changes in climate as manifested in changes in seasonal rainfall and temperature increases, the DWR in all climate types across scenarios would increase except in climate type I. The reduction in DWR in climate type I could be due to the increase in rainfall during the MAM season, which caused the lower irrigation

requirement for land preparation in June. These reductions in DWR appeared in most of the scenarios during normal and wet years. The favorable abatements in irrigation requirements in the Maringalo site reached as much as - 12% (1.14 l/s/ha) relative to the baseline. The declines in DWR are most prevalent during wet years. There were also upsurges in DWR during dry and normal years in Maringalo, which could reach as much as + 11% (1.45 l/s/ha) and + 7% (1.39 l/s/ha), respectively.

Notably, there was a decline in irrigation requirements in Kabulnan2 which occurred only in the RCP4.5 mid-twenty-first century. The reduction in irrigation requirement in Kabulnan2 occurred on the planting of the 2nd 20% covered area. This is due to the projected higher effective rainfall in April and May during the dry years in the RCP4.5 mid-twenty-first. This decline in DWR suggests that the Kabulnan2 site under climate type IV could be the most resilient against climate change in terms of irrigation requirements.

On the other hand, the rest of the selected sites' DWR was estimated to go up and would peak as temperature increases and seasonal rainfall subsides. The impact of climate change could be worst during dry seasons especially in the Maasin site where the upsurge in DWR could reach as high as + 43% (1.95 l/s/ha) under the RCP8.5 scenario late twenty-

Table 2 Percent changes in diversion water requirement due to climate change

Century	RCP	Diversion water requirement, l/s/ha			Percent change		
		Dry years	Normal years	Wet years	Dry years	Normal years	Wet years
Climate type I: Maringalo							
		Baseline	1.30			-	
Mid-21st	RCP 4.5	1.21	1.21	1.29	- 7%	- 7%	- 1%
	RCP 8.5	1.30	1.16	1.21	0%	- 11%	- 7%
Late 21st	RCP 4.5	1.29	1.39	1.14	- 1%	7%	- 12%
	RCP 8.5	1.45	1.39	1.23	11%	7%	-5%
Climate type II: Daet							
		Baseline	1.43			-	
Mid-21st	RCP 4.5	1.54	1.73	1.54	7%	21%	7%
	RCP 8.5	1.73	1.61	1.61	21%	13%	13%
Late 21st	RCP 4.5	1.68	1.66	1.70	18%	16%	19%
	RCP 8.5	1.75	1.80	1.57	23%	26%	10%
Climate type III: Maasin							
		Baseline	1.36			-	
Mid-21st	RCP 4.5	1.63	1.68	1.63	20%	24%	20%
	RCP 8.5	1.82	1.68	1.57	34%	24%	16%
Late 21st	RCP 4.5	1.79	1.71	1.91	32%	26%	41%
	RCP 8.5	1.95	1.79	1.59	43%	32%	17%
Climate type III: Abuan							
		Baseline	1.3			-	
Mid-21st	RCP 4.5	1.31	1.46	1.36	9%	0%	1%
	RCP 8.5	1.34	1.49	1.46	3%	14%	13%
Late 21st	RCP 4.5	1.34	1.50	1.61	3%	15%	24%
	RCP 8.5	1.36	1.50	1.63	5%	15%	25%
Climate type IV: Kabulnan2							
		Baseline	1.29			-	
Mid-21st	RCP 4.5	1.21	1.36	1.32	- 6%	6%	3%
	RCP 8.5	1.32	1.30	1.38	3%	1%	7%
Late 21st	RCP 4.5	1.32	1.34	1.55	3%	4%	21%
	RCP 8.5	1.29	1.46	1.54	0%	14%	19%

first century. The Maasin site also holds the record for the highest projected adverse increase in DWR during normal climate conditions, which is + 32% (1.79 l/s/ha) that also occurred in the RCP8.5 scenario late twenty-first century. Among the selected watershed, the Maasin site could be the most vulnerable to climate change in terms of irrigation requirements.

Moreover, the Daet site under climate type II could have an unfavorable increase in DWR that could range from + 13% (1.61 l/s/ha) to + 26% (1.80 l/s/ha) during normal climate conditions, + 7% (1.54 l/s/ha) to + 23% (1.75 l/s/ha) during dry years, and + 7% (1.54 l/s/ha) to + 19% (1.70 l/s/ha) during wet conditions. Similarly, the Abuan River under climate type III could have an unfavorable escalation in DWR by + 0 to + 15% (1.5 l/s/ha) during normal years, + 3% (1.34 l/s/ha) to + 9% (1.31 l/s/ha) during dry years, and + 1% (1.36 l/s/ha) to + 25% (1.63 l/s/ha) during wet years. The Kabulnan2 River under climate type IV had a projected DWR increase of + 1% (1.30 l/s/ha) to + 14% (1.46 l/s/ha) during normal years, little to none or + 0% to + 3% (1.32 l/s/ha) during dry years, and + 3% (1.32 l/s/ha) to + 21% (1.55 l/s/ha) during wet years. The increase in rainfall in MAM season during dry years abated the increase in crop water requirement brought about by a temperature increase in Kabulnan2.

Results of this study showed that climate change could increase the irrigation requirements in the Philippines by up to almost half of the baseline value. Similarly, climate change impact assessments in other countries showed the same trends. For instance, in Taiwan, it was predicted that a surge in paddy irrigation requirement would be incurred due to climate change amounting to as much as + 7.1% increase (Lee and Huang 2014). Boonwichai et al. (2018) proved the same trend of climate change impacts on crop water requirement in Thailand that could, in turn, increase irrigation requirement as well as a decrease in rice yield by up to - 14%. A case study by De Silva et al. (2007) reported that the paddy irrigation requirement in Sri Lanka could rise by as much as + 45%, which is comparable to the increase in DWR accounted for in this study. On the other hand, this study showed that the impact of climate change on DWR could also be favorable sometimes in other parts of the country. This has been proven in the case is the Maringalo site where DWR was decreased across some scenarios due to a timely increase in rainfall and a scenario in the Kabulnan2 site. Droogers (2004) also found the same encouraging results of climate change assessment in irrigation requirements in Sri Lanka due to higher carbon dioxide (CO₂) and a slight increase in rainfall but stressed the threats of more frequent extreme climate conditions in the future. In contrast, a hydrologic assessment study by Puno et al. (2019) showed an increase in evapotranspiration even with 10% increase in rainfall, which the authors considered not significant. However, this increase in ET in the said hydrologic assessment was primarily due to the increase in forest vegetation that they simulated along with the 10% increase in rainfall. The present study showed that a favorable, substantial, and timely increase in rainfall of more than 10% especially during wet years could reduce the water supply needed in irrigation systems for rice production. Furthermore, this part of the study concludes that changes in rainfall and temperature at the optimum level for crop production could bring a positive impact on diversion water requirements. However, beyond the optimum levels of climate for a favorable production, DWR is adversely affected. These projections on the impacts of climate change on irrigation requirements are manifestation or indication that long-term projects, policies, and programs to adapt and minimize the future adverse crop production situations should be prioritized. Climate change takes its toll on food security and is predicted to continue until the end of the twenty-first century. The case of Maringalo, where there was a favorable decline in DWR, underscores the need to modify or adjust cropping calendars in irrigation systems especially in large ones to

minimize the adverse impacts of climate change on crop water use and optimize water resources during extreme climate conditions.

While this study has generated results that may be used for irrigation system planning, uncertainties in the estimates of diversion water requirements as influenced by climate change are nonetheless recognized. The potential sources of uncertainties include the CROPWAT model parameter uncertainties, the assumption for irrigation efficiencies, and the inherent uncertainties in the climate projections. The CROPWAT model has been proven to satisfactorily replicate the eddy covariance-derived evapotranspiration. Nevertheless, despite these inherent uncertainties, the projections and estimates of irrigation diversion water requirement generated in this study are within the typical value of water duty of 1.5 l/s/ha used by NIA for irrigation system planning purposes, which they adopted from the Food and Agriculture Organization typical values for rice (Brouwer et al. 1992). There are however regional differences in irrigation water requirements due to climatic, soil, and hydrologic differences, and hence, the actual water duty may be lower than or greater than 1.5 l/s/ha. The impacts of these spatial differences can be observed in the CROPWAT estimates of irrigation requirements across the country. The CROPWAT-based estimates of DWR seemed that climate change had the major impact. A wider variability in DWR was observed across sites per climate change scenario compared to that of the baseline estimates. The spatial variability in the baseline values of DWR reflects the differences in CROPWAT input such as the soil and planting dates. This study provided more suitable values of the water duty or diversion water requirement by accounting for these spatial variabilities. Furthermore, the soundness of the approach employed in this study increases the confidence in the validity of the results generated.

4 Conclusion

The climate change impact assessment performed in this study revealed that the seasonal changes in rainfall and continuous increase in temperature could lead to a significant increase in diversion water requirements across climate types in the Philippines. Consequently, this could pose potential problems on irrigation water supply and irrigability of crop production areas in the country. The CROPWAT estimation of crop water requirements was satisfactorily calibrated and validated using the eddy covariance method. Results suggest that without any intervention, the available water supply could hardly sustain the increasing water demand for future crop production in the country. Climate-based adjustment of crop calendars may be one of the appropriate strategies to address these issues. As climate changes, so are the timing of rainfall. This study also proved that CROPWAT could be a helpful tool in developing crop calendars to adapt rice production to climate changes and minimize its impacts. This has been manifested in the Maringalo site where there were favorable decreases of diversion water requirement across climate change scenarios due to the right timing of planting just in time for the rainfall. This research offers an alternative approach in the development of cropping calendars incorporating the effects of climate change for future irrigation system planning and development. More importantly, the results of this study could be used for determining the design of irrigable areas and as part of planning and design criteria for dams and reservoirs and consequently contribute to climate proofing of irrigation systems.

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Data availability Data will be available upon request in responsible agencies.

Declarations

Conflict of interest The authors declare no competing interests.

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