IMPACT OF CLIMATE CHANGE ON TIDAL IRRIGATION CASE STUDY: TERANTANG IRRIGATION UNIT, INDONESIA

MAYA AMALIA ACHYADI
Saga University, Saga, Japan, 17654904@edu.cc.saga-u.ac.jp
Lambung Mangkurat University, Banjarmasin, Indonesia

KOICHIRO OHGUSHI
Saga University, Saga, Japan, ohgushik@cc.saga-u.ac.jp

TOSHIHIRO MORITA
Saga University, Saga, Japan, toshihiro@buz.bbiq.jp

ABSTRACT

Climate change is a highly serious problem on agricultural sector and potential new problems sustainability of food production. Climate change will generate a hazard on alteration of rainfall patterns, sea water level rise and increasing of temperature. Phenomenon of climate change in Indonesia indicated by an impact on water availability. Tidal irrigation is an irrigation system that is widely used by farmers in Indonesia such as Terantang Irrigation unit. Tidal irrigation is a different system from other irrigation systems, it takes the advantages of ocean tides and push the river fresh water to the primary canal on the irrigation network. Terantang unit is highly dependent on the water level of Barito River as a source of water supply in addition to the rainfall. Projected rainfall during the 2050s and 2090s are obtained from two circulated models for projected temperature and rainfall data under CMIP5 with 4.5 and 8.5 RCPs scenario. Based on the future effective rainfall water requirement is estimated. The requirement for irrigation water is not only sufficient discharge, but also the appropriate water level. This research developed a MIKE 11 model of an existing canal network to simulate the impact of rising sea level elevation. Model prediction indicates that sea level rise impact the water level requirement of paddy fields.

Keywords: Climate change, tidal irrigation, Barito, Terantang, MIKE 11

1. INTRODUCTION

As a country with fourth rank of population in the world, Indonesia is vulnerable country facing the food insecurity. Agro-ecosystem in Indonesia are classified into three different class: irrigation system, climate condition and tidal type (Sulaiman, et al., 2019). Rice as a staple food in Indonesia generally cultivated on the irrigated paddy field area. In 2018, paddy field area with irrigation system is 58.13% (Ministry of Agriculture, 2018). Indonesia's government has been developing lowland area into agriculture site in South Kalimantan province. Indonesia with 33.4 million hectares' lowland area and less than 10% of this area is used for rice fields (Istianto, et al., 2018). Over the past decades, climate change is a serious problem in a lot of sector such as water availability, agriculture and food security. Precipitation in Southeast Asia region predicted will be increase from 1% to 12% by the end of 21th century (IPCC, 2007).

Tidal irrigation in lowland areas is used to cultivate rice by indigenous people who live on river side area. Since hundreds years ago, Banjar people who live near Barito River built canal to irrigate their rice field area. These traditional system constructed canal with 2-3 m of width and 0.5-1.0 m of depth called *handil* (Sulaiman, et al., 2019). Tidal irrigation system not only provided water from river but also effective rainfall.

These study objectives are to calculate the water requirement analysis due to the climate change consideration on temperature and rainfall and to predict the impact of sea level rise on the water level requirement on the Terantang irrigation unit by 2050s and 2090s.

2. MATERIALS

2.1 Study area

Terantang irrigation unit in Barito Kuala Regency, South Kalimantan Indonesia is the study area of this reseach. Barito Kuala is a tropical monsoon climate with 200 mm of average rainfall in wet season and less than 100 mm when the dry season start in July until September (Ar Riza & Anwar, 1997). This tidal irrigation unit with 3200 hectare of agriculture area lies in the eastern region of Barito river banks. Terantang area is the pilot project for lowland agriculture with tidal irrigation in 2019. Terantang irrigation unit shown in Figure 1, includes primary canal with 8.9 km of length and 50 m of width, secondary canal with 45 m of width and tertiary canal on the both side. Tertiary canal has 47 channels and 39 channels on left side and right side respectively. Terantang irrigation units has a pond at the end of main canal, dimension of tidal pond is 400 m of length and 300 m of width. Topography condition is relatively flat around 3%.

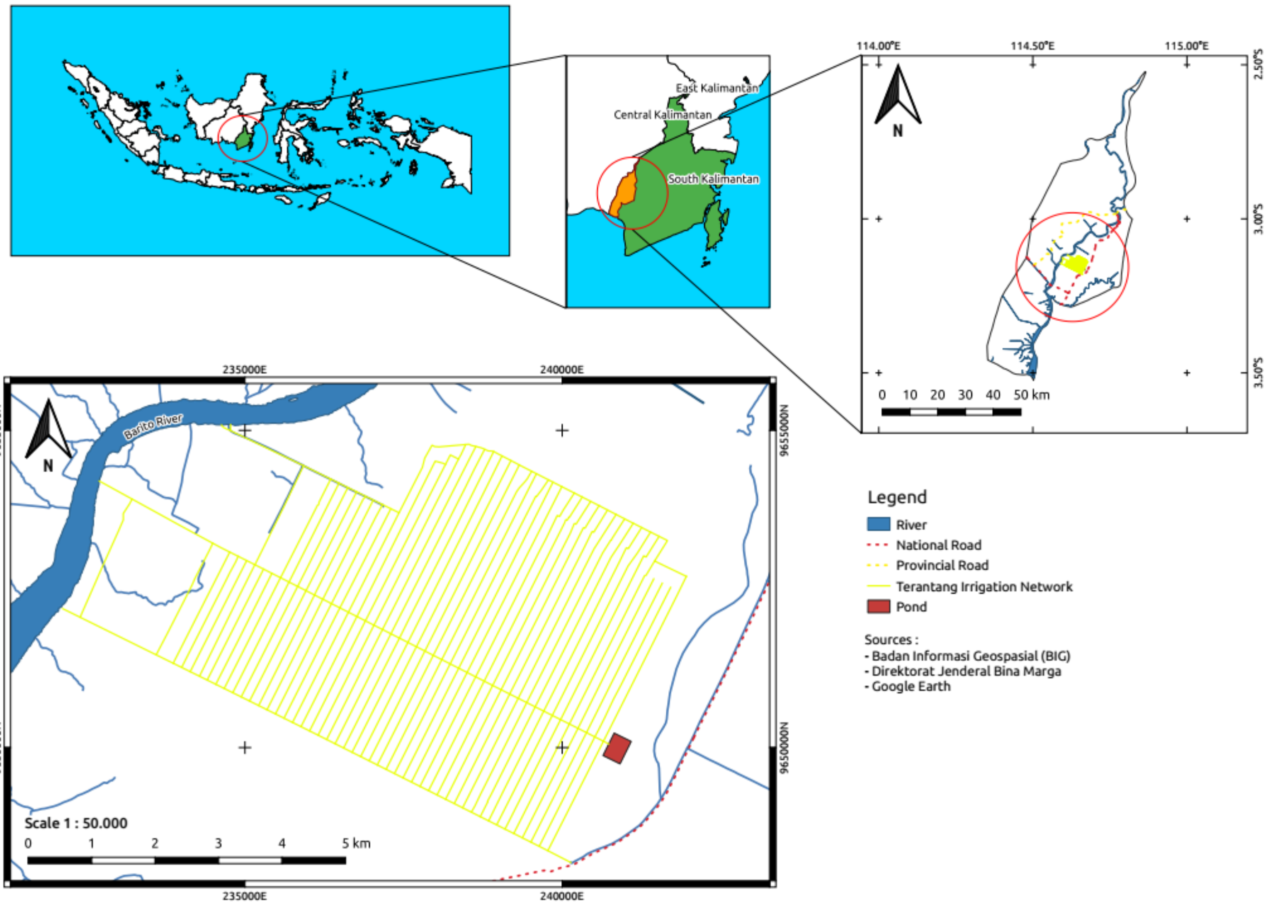

Figure 1. Terantang irrigation unit, Barito Kuala Regency, South Kalimantan Indonesia

2.2 Climate Change Scenarios

In this research two scenarios were considered in predicting climate change, Representative Concentration Pathways (RCP) 4.5 and 8.5 from two General Circulation Models (GCMs). All detailed information about RCP are shown in Table 1. CMIP5 GCMs as MRI-CGCM3 and CNRM-CM5 are used to simulate the future meteorological value such as temperature and rainfall. Description of two GCMs models are shown in Table 2.

Table 1 IPCC climate scenarios specified in Representative Concentration Pathways

Scenarios	Radiative Forcing	Temperature anomaly	Pathway
RCP 4.5	Stabilisation without overshoot pathway to 4.5 W/m^2 at stabilisation after 2100.	2.4	Stabilisation without overshoot
RCP 8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.	4.9	Rising

Source : (Htut, 2015)

Table 2 CMIP5 GCMs data sources

Models	Description	Research Centre	Grids (Long-Lat)
CNRM-CM5	Centre National de Recherches Météorologiques Climate Model version 5	CNRM/Centre Européen de Recherche et Formation Avancée en Calcul Scientifique, France	256 × 128
MRI-CGCM3	Meteorological Research Institute Coupled General Circulation Model version 3	MRI, Japan	320 × 160

Source : (Htut, 2015)

The simulations cover period from 1979 to 2005 (historical) and from 2041 to 2100 with CMIP5 under two scenarios. The projected simulations are analyzed for two periods: the 2050s (2041-2060) and 2090s (2081-2100) relative to the 1979-2005 climatology historical data.

Due to rising sea levels, Southeast Asia, especially Indonesia, is one of the countries with the greatest impact on climate change in the world (Nicholls & Cazenave, 2010). A lot of economics activities are developed in coastal area; Terantang Irrigation unit is the one of tidal irrigation unit where located along Barito River in Kalimantan. Tidal irrigation is irrigation technic which takes an advantage when high tide occurs and water flows to irrigation canal. More than 120 thousand hectares' agricultural area in Barito Kuala including the Terantang units will be affected by sea level rising (Saidy & Azis, 2009). Irrigation technic that takes advantages by tidal fluctuations has 4 classification types based on the water level condition. The classification of the tidal lowland is pesented on Table 3 and the water level of tidal irrigation in relation to agricultural crops requirement can be seen on Table 4.

Table 3 Classification of Tidal Lowland

Type	Classification
A	Fields can be flooded at least 4-5 times during neap-spring tide cycle both in wet and dry season
B	Fields can be flooded at least 4-5 times during neap-spring tide cycle both in wet season only
C	Fields cannot be regularly flooded during high tides.
D	Fields not affected by tidal movement.

Source : (Istianto, et al., 2018)

Table 4. Tidal irrigation water level requirement

Class	Tidal Irrigation depth (m)	Cultivation
1	>0.25 (above the ground surface)	Not suitable
2	0.0-0.25 (above the ground surface)	Rice Crops
3	<0.0	Dryland Crops

Source : (Istianto, et al., 2018)

3. METHODS

3.1 Evapotranspiration and Irrigation Water Requirement for paddy

Evapotranspiration was calculated by standard condition, which means paddy is cultivated in the large paddy fields with consideration of well fertilized and disease free (Lee & Huang, 2014). Crop water demand equals by crop evapotranspiration under standard condition, and the formula expressed as:

$$ET_c = K_c \text{ x } ET_0 \quad (1)$$

where ETc is crop evapotranspiration under standard conditions (mm/day); Kc is crop coefficient (dimensionless); ET_0 is reference evapotranspiration (mm/day).

To estimate the reference of evapotranspiration in this study *Penman-Monteith* formula was used. *Penman-Monteith* formula is recommended as a standard for calculate evapotranspiration value worldwide. Equation of *Penman-Monteith* formula as shown below:

$$ET_0 = \frac{0.408\Delta(Rn - G) + \gamma 900u_2/(t + 273)(es - ea)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where:

ET_0 = evapotranspiration (mm/day),

Δ = gradient of saturation vapor pressure vs temperature curve (kPa/°C),

Rn = net radiation (MJ/m^2day),

G = ground surface soil heat flux density (MJ/m^2day),

t = daily average temperature (°C), u_2 = daily wind velocity at 2 m (m/s),

es = vapor pressure at saturation stage (kPa), ea = vapor pressure at actual stage (kPa),

es - ea = the saturation vapor pressure deficit (kPa),

γ = constant value of psychometric (kPa/°C).

In this study IWR simulated 15-day evapotranspiration values and effective rainfall during cultivation period for local paddy varieties with Standard IWR formula that shown in equation below.

$$IWR = ET_o \times Kc \quad (3)$$

where:

IWR = Irrigation water requirement (mm/d),

ET_0 = evapotranspiration (mm/d),

Kc = Crop coefficient

3.2 Sea level Rise and Tidal Irrigation

According to observations from NOAA satellites in Figure 2, sea level rise in Indonesia from 4.9 to 6.6 mm/year (Rahmadi, et al., 2010). Based on previous research by Triadi and Gifariyono (2014), we assume that sea level rise will increase 0.2 m in 2050 and 0.5 m in 2090 in this study.

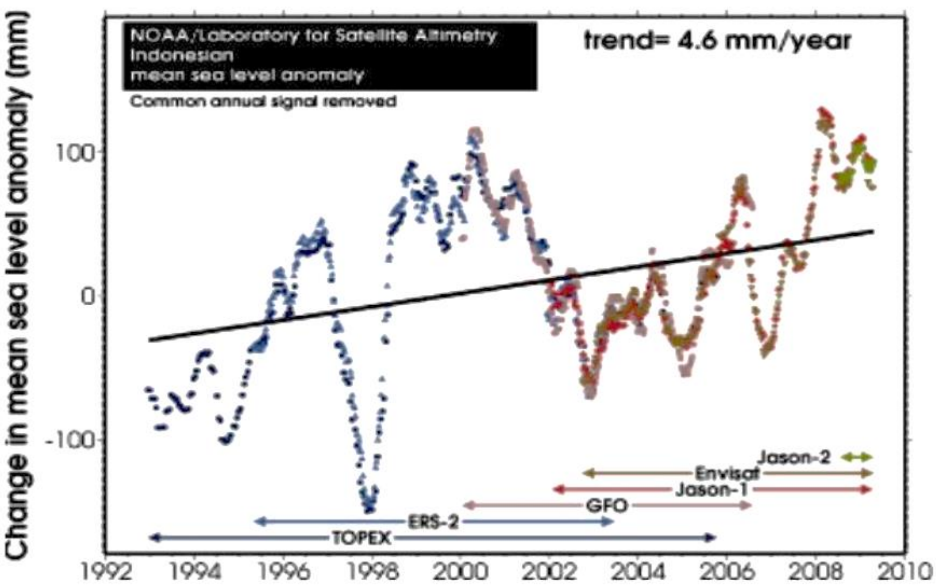

Figure 2. Increasing of Mean Sea Level in Indonesia
Source: (Triadi & Gifariyono, 2014)

The water level on the tidal irrigation is analyzed by mathematical modeling. On this study, MIKE 11 was chosen to simulate the water level in Terantang area. Equations in MIKE 11 are St. Venant equations as shown in equation 4 and 5.

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q \quad (4)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha\frac{Q^2}{A}\right)}{\delta x} + gA\frac{\delta h}{\delta x} + \frac{gQ|Q|}{C^2AR} = 0 \quad (5)$$

where:

Q = discharge (m^3/s)
x = longitudinal channel distance (m)
A = cross-sectional area (m^2)
q = lateral inflow (m^3/s)
t = time (s)
h = flow depth (m)
g = gravitational value
C = Chezy coefficient
R = hydraulics radius (m)

4. RESULTS AND DISCUSSION

4.1 Water Requirement on future simulation

Figure 3 shows that present condition of IWR maximum value at 23.30 m^3/s in September first period, this result not only appears in current condition but also in both of future simulated models. Maximum values of future simulated IWR in 2050s at 36.25 m^3/s and 35.22 m^3/s for CNRM-CM5 and MRI-CGCM3 respectively. This condition occurred because of the dry season in Indonesia starts from April to September, on the same time cultivation period with generative stage start from September to the end of October. Pattern of irrigation water requirement on wet season for current and simulated values are similar. Wet season starts from October to March on the following year, results present light differences pattern regarding to two models, CNRM-CM3 shows that prediction in 2090s increasing by 0.91 m^3/s compare to 2050s in March. Other models, MRI-CGCM3, prediction value is decreasing by 0.87 m^3/s between 2050s to 2090s in March. This condition appear because of total effective rainfall in March from two models are different. Total future effective rainfall simulation in March CNRM-CM3 is lower than MRI-CGCM3.

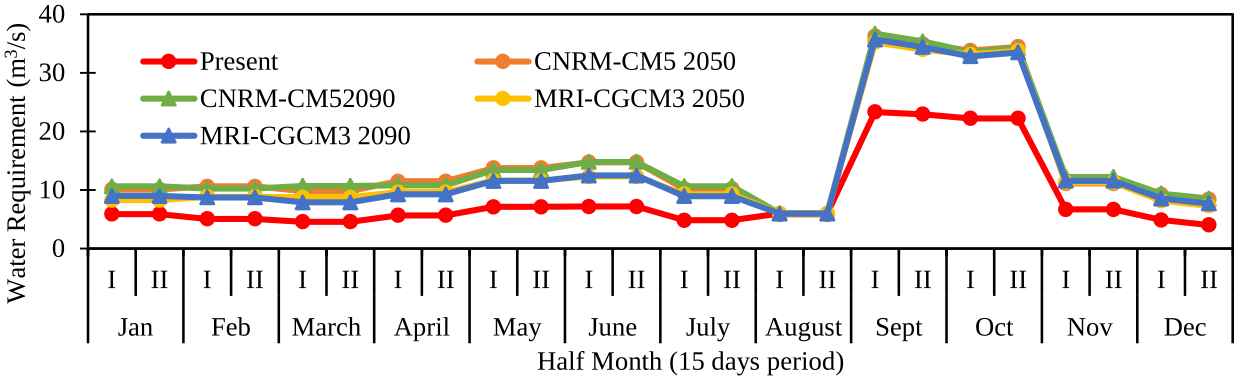

Figure 3. Current and future simulated irrigation water requirement at Terantang under RCP 4.5.

Figure 4 present the result of current condition and future simulated irrigation water requirement under RCP 8.5 scenarios. Prediction of IWR in 2050s to 2090s under RCP 8.5 scenario slightly different compared to others scenarios. According to the maximum values, 29.8 m^3/s, it is lower than RCP 4.5 scenario however September is the same time produce the maximum water demand. In this scenarios water requirement in February 2050s is higher than 2090s, in the other hand start from May until July 2090s values is higher than 2050s. This pattern appears because of effective rainfall values and evapotranspiration change due to climate change scenarios.

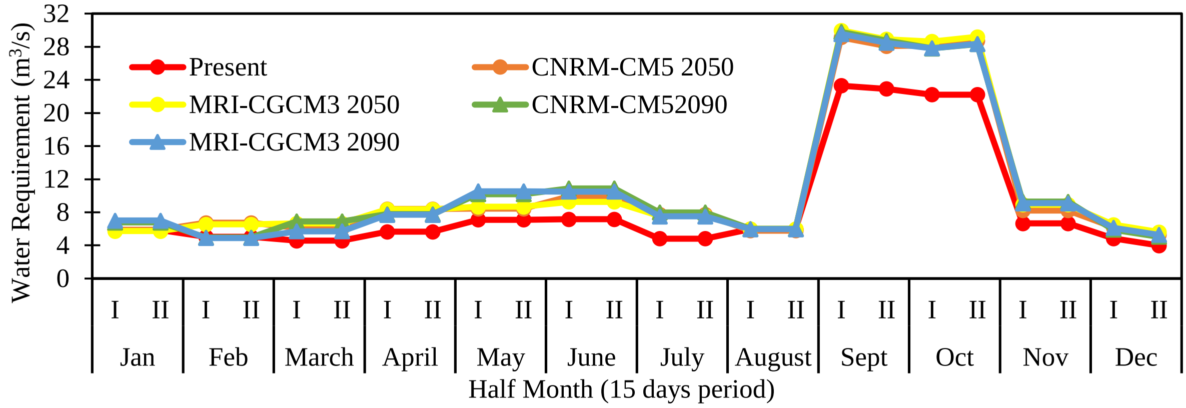

Figure 4. Current and future simulated irrigation water requirement at Terantang under RCP 8.5.

4.2 Future Water Level Simulation

Future water level simulation in Terantang is analyzed by using MIKE 11 model. Current condition of water level, increasing by 20 cm and 50 cm are three scenarios conducted in this research. These three scenarios provided the estimating discharge and water level at Terantang Irrigation unit.

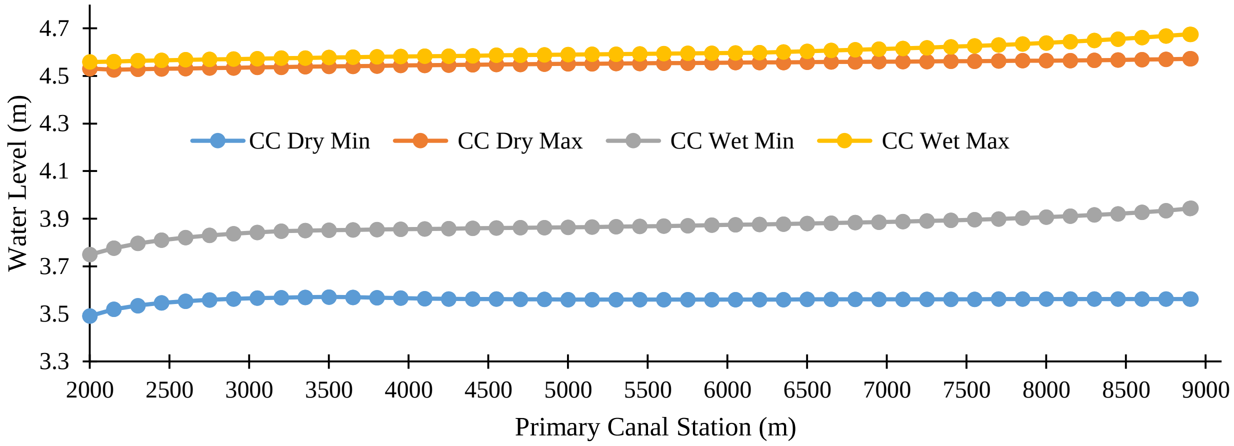

Figure 5. Water level current condition (CC) in wet season and dry season (Case A)

Figure 5 presented simulation of water level on current condition in both season (Case A), wet and dry season. Wet season data from 11th January until 25th January and dry season data from 11th August until 25th August both season collected data in 2018. Figure 5 shows the differences maximum water level in wet season and dry season is around 10 cm on the other hand when the dry season occurred minimum value of water level differences is about 20-30 cm. This condition appears because of the tidal fluctuation in dry season between lowest and highest tide differences about 2.1 m. At this simulation the water level requirement of rice field area is not suitable because of the appropriate water level at +5m from local benchmark. Even though in this simulation the discharge value is higher than requirement at 25 m^3/s.

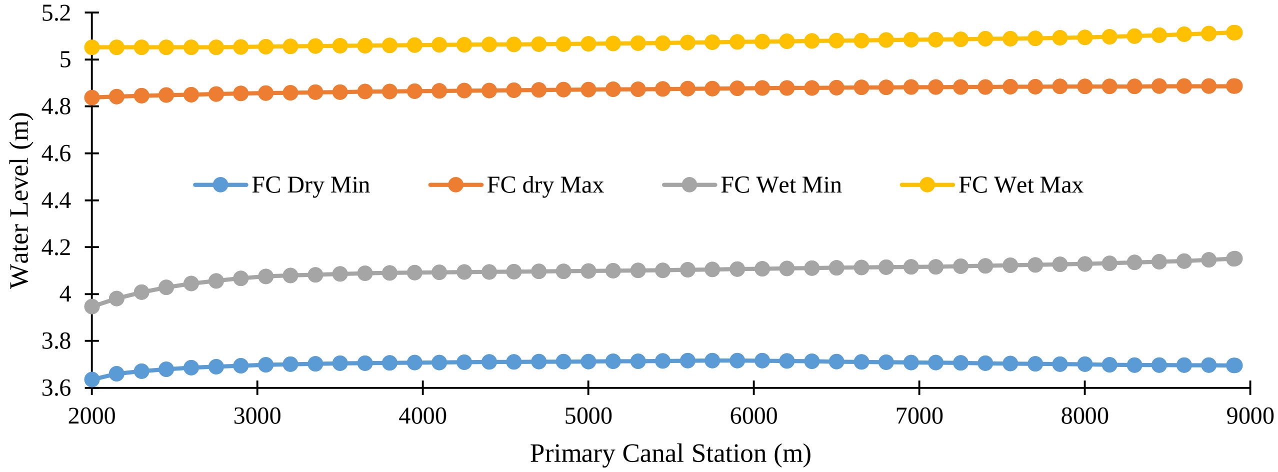

Figure 6. Future condition (FC) water level simulation in wet and dry season by 0.2m increasing value of current condition (Case B)

Figure 6 shows the differences maximum water level in wet season and dry season is around 20 cm on the other hand when the dry season occurred minimum value of water level differences is about 30-40 cm. At this simulation the water level requirement of rice field area is suitable because of the appropriate water level more than +5m from local benchmark but this condition only appears in wet season. In Case B simulation, we can see the dry season water level lower than 5m. This condition not suitable for rice cultivation process, from Case A and B the performance of Terantang irrigation network is low because of the water level condition.

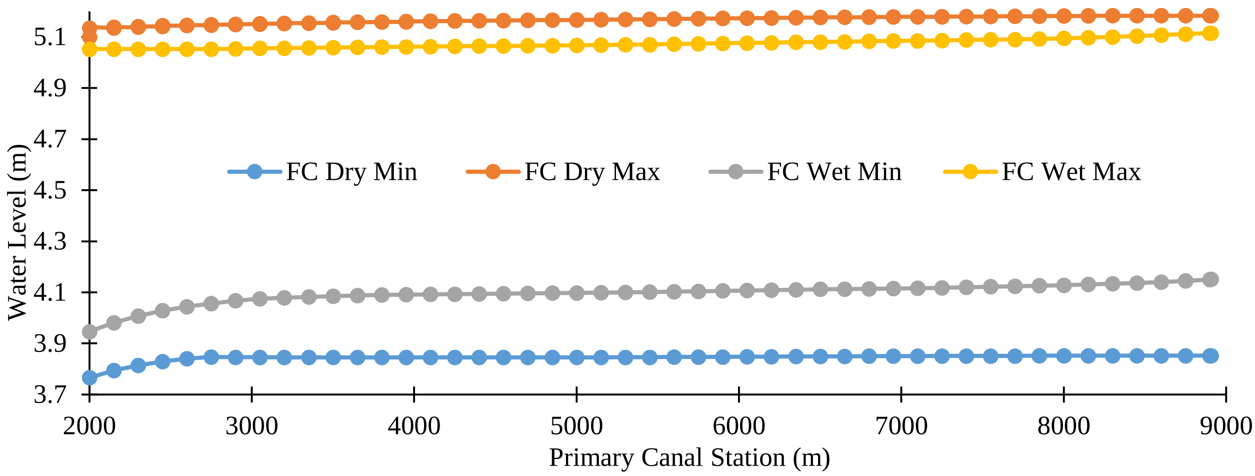

Figure 7. Future condition (FC) water level simulation in wet and dry season by 0.5m increasing value of current condition (Case C)

Figure 7 presented simulation of water level on increasing water level by 0.5 m in both season (Case C), wet and dry season. In this simulation maximum value also reach to 5 m of water level in both season, when the high tide occurs the level of paddy field requirement will reach the suitable condition but on the contrary when the low tide occurs minimum water level will not suitable for rice cultivation, because of the water level lower than 5m on the both season. Discharge value in this Case C simulation reach the maximum in wet season at 49 m^3/s, it means suitable for water irrigation requirement at Terantang network.

Simulation of Case A, B and C have similar pattern of water level condition. Maximum value in wet season for Case C will reach the optimum condition but not sufficient for Case A and B. This results will have affected the cultivation process, especially the minimum value on both season.

5. CONCLUSIONS

In this study, the impact of climate change on water irrigation demand and availability in Terantang, South Kalimantan, Indonesia was analyzed. "In the two time periods of 2050s and 2090s, the irrigation water requirement calculated using the future simulated weather data based on the CMIP5 scenario combined with RCP 4.5 and RCP 8.5 GCMs models. Assuming that the water level rises by 0.2 m and 0.5 m respectively, the future water level and discharge conditions are analyzed through the MIKE 11 model.

Results show an increase in irrigation water requirements under two scenarios compared with the present condition. However, future simulation under RCP 8.5 in both time periods is decreasing compare to RCP 4.5 due to the increasing value of effective rainfall. The simulation of available water in 2090s period with the assumption an increase of 0.5 m during the rainy season will meet the appropriate conditions for the water level requirements of the paddy field. On the other hand, when the dry season occurs the water level lower than optimum conditions. Although the discharge values on both season are higher than required values. There is an opportunity to conduct further research to study how to improve the water management in the Terantang tidal irrigation network by placing some hydraulic structures or pumps, especially during the dry season simulation.

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