Assessing effects of climate change on irrigation water demand in the Lombok River Basin, Indonesia

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Abstract. Irrigation water demand in the command area is affected by rainfall and climate conditions in the river basin. In climate change conditions, rainfall and temperature are predicted to increase and projected to impact irrigation water requirements significantly. Therefore, understanding the climate change effects on irrigation demand in the command area is significant to the river basin manager and planner for managing water resources effectively. This study aims to predict the impact of climate change and irrigation efficiency improvement on the irrigation water requirement in 2032-2040. This study used the CropWat model to estimate irrigation water requirements in 1995-2005 and 2032-2040. Irrigation water demand in the Dodokan watershed as a part of the Lombok river basin was computed using the historical rainfall and climate data from observation stations. Further, the observed data from 2006 to 2014 were projected into climate change in 2032-2040 as an input for the model to predict the demand in corresponding years. Result suggests that the change of annual irrigation water demand in the Dodokan watershed was expected to rise by 1.61% in 2032-2040 compared with 1995-2005, and irrigation efficiency improvement effort would decrease the demand -18.18% in the climate change period.

Keywords: climate change, irrigation, water demand, water requirement

1. Introduction
The climate change phenomenon has been identified in some countries and also in Indonesia. Globally, IPCC [1] projected a change in global mean surface air temperature in 2016-2035, likely 1°C above the mean from 1850 to 1900. Regarding Lombok Island, McGregor et al. [2] projected the atmospheric model. They found that for 2060 rainfall increased between zero to 5-10% in DJF, and temperature increased at a range of 1.6°C to 2°C.

Some studies have been done to identify the effect of climate change in many sectors, especially in water resources [3–5]. Climate change effect on irrigation water demand was predicted by Fischer et al. [6] and warned that the demand would rise to 40% in the unmitigated climate irrigation area. Several efforts in dealing with the climate change impacts have been investigated, such as readjustment sowing date [7,8], shifting farming practices [9], rice variety [10], farmer adaptation [11], and shift in the growing season [12]. However, relatively few studies have shown the contribution of mitigation efforts in the irrigation area to face the future climate.
Some recent literature [13–17] showed that the irrigation water demand change would be different, e.g., increasing and decreasing, depending on the crop types and locations in future climate change. Especially for paddy, increasing irrigation water demand in the future was reported by some literature. Achyadi et al. [18] estimated paddy water requirement at vegetative stages would increase approximately 56% in the dry season and 25% in the dry season in September and October for paddy in South Kalimantan, Indonesia. Ding et al. [8] stated that irrigation water requirement would increase in China accompanied by decreasing future rice yield. Shahid [19] found that required water for land preparation and daily evapotranspiration would be increased. And there would be a significant change in total irrigation due to temperature increase in the future in Northwest Bangladesh. Kamruzzaman et al. [20] expected that irrigation water demand in Seoul, South Korea, would increase 3.21% in 2040 compared to the 1976–2005 periods. To date, some studies have confirmed the effects of climate change on irrigation water demand in the rice yielded countries.

On the other hand, climate change also impacts streamflow as the primary source of irrigation systems [21,22]. Some climate parameters contributing to increasing irrigation water demand were identified in some literature, such as temperature and humidity [23]. Kamruzzaman et al. [20] showed that the evaporation tended to increase approximately 0.12%, 2.21%, and 7.81% during the 2010s, 2040s, and 2070s, respectively, due to the rising of temperature in South Korea.

The current study aims to predict the impacts of climate change on the irrigation water demand in the future. The study was conducted based on the predicted climate change data from MIROC5 (RCP4.5) climate change projection and current climate data obtained from Indonesia’s Meteorological, Climatological, and Geophysical Agency. Irrigation efficiency was considered in this study to determine the impact of irrigation efficiency improvement in the watershed. Four scenarios were developed for comparing the water demand in the present and future scenario in combination with irrigation efficiency improvement up to 70% in all watersheds. The result of the study may help decision-makers and stakeholders in irrigation strategies decision to anticipate conditions in effort facing the climate change in the future.

2. Material and Method

2.1. Irrigation Water Requirement

Climate condition, crop type, area, soil, irrigation efficiency, command area, and growing stages are major factors for calculating irrigation water demand requirements [24]. CROPWAT 8.0 is a widely used model to analyze crop water demand requirements in the irrigation command areas [13,25,26]. The model was developed by FAO in 1991 and applied the Penman-Monteith method to estimate ETo, ETc, and CWR. ETc in the CROPWAT model calculated by,

$$ET_{crop} = K_c \times ET_0$$ (1)

where, ET_o = reference evapotranspiration in mm/day; K_c = crop coefficient at a specific growth stage; ET_crop = actual evapotranspiration by the crop in mm/day. Parameter Kc relates with crop type and growing stage. While ET_o depends on relative humidity, wind speed, sunshine hours, and temperature. The Penman-Montenth is a recommended method by FAO for estimating ET_o.

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}$$ (2)

Where, R_n = net radiation at the crop surface in MJ/m^2/day; G = soil heat flux density in MJ/m^2/day; T = mean daily air temperature in °C; U_2 = wind speed in m/s; e_s = saturation vapor pressure in kPa; e_a = actual vapour pressure in kPa; D = slope of vapour pressure curve in kPa/°C; e_s - e_a = saturation vapour pressure deficit in kPa; and c = psychometric constant in kPa/°C. The crop water requirement in SWAT model is calculated by formula:
\[ Q_{gross} = \frac{1}{e_p t} \left[ 0.166 \times A_{scheme} \times \sum_{i=1}^{n} \frac{A_{crop}}{A_{scheme}} \left( ET_{ci} - P_{eff} \right) \right] \]  

where, \( Q_{gross} \) = monthly agricultural water requirement of irrigation scheme in m³/day; \( i \) = crop index; \( A_i \) = command area in hectare; \( ET_{ci} \) = crop evapotranspiration in mm/day; \( P_{eff} \) = the effective rainfall in mm/day; \( e_p \) = irrigation efficiency ≤ 1, dimensionless; \( t \) = time operational factor ≤ 1, dimensionless.

The effective rainfall was calculated by the USDA Soil Conservation Service method:

\[ e_p P_{eff} = P_{tot} \times \left( \frac{125 - 0.2TR}{125} \right) \]  
\[ \text{for total rainfall} < 250 \text{mm} \]  

\[ P_{eff} = 125 + 0.1 \times P_{tot} \]  
\[ \text{for total rainfall} > 250 \text{mm} \]

where \( P_{eff} \) = the effective rainfall in mm; and \( P_{tot} \) = the total rainfall in mm.

2.2. Irrigation Efficiencies
Enhancing irrigation efficiency is applied to improve the use of available water resources for irrigated land. The irrigation efficiency is measured from some points of view: system performance of irrigation system, water application uniformity, and the crop response to irrigation [27]. Efficiency in irrigation system performance is commonly divided into water conveyance efficiency. It is defined as reached water to the field and diverted irrigation water source ratio, application efficiency, storage efficiency, seasonal irrigation efficiency, irrigation uniformity, emission uniformity, and water use efficiency [28]. Outdate infrastructures and inefficient watershed management are sources that affect irrigation efficiency in an irrigation system [29].

2.3. The study area
The Lombok river basin is located in Lombok Island, Nusa Tenggara Barat Province. The basin covers 4738.65 km² with a total population of 3,394,280 people [30] between 8°15' S to 9°10' S latitude and 116°00’ E to 116°45’ E longitude. Mean annual rainfall in the east varies between around 1571 mm to 1368 in the west [31]. The temperature ranges between 23.7°C to 26.5°C throughout the year [32]. Mountain path topography from Mount Rinjani dominates the basin area. The principal crop planted is paddy, followed by maize and soybean as secondary crops. The croplands in the Lombok river basin are predominantly irrigated, spread from the west to east part of the basin. The total cropland area in Lombok was 130,335 hectares consisting of 110,027 hectares of irrigated area and 20,308 hectares of rainfed [30]. Dodokan, as the largest watershed in the Lombok river basin, has been selected in this study. Geographically, the watershed area extends from 8°33’57.26” S to 8°52’51.22” S latitude and 116°22’11.33” E to 116°22’11.33” E longitude [33]. Dodokan watershed encompasses about 578.62 km². The Dodokan river traverses a stretch of 179.10 km, originating from Mount Rinjani. The Dodokan watershed extends from Kabupaten/Sub-district Lombok Barat (18.90%) and Lombok Tengah (81.10%). The soil type in the Dodokan watershed is dominated by brown and reddish-brown Mediterranean soil [34].

2.4. Datasets
Required data for analysis, including maximum and minimum temperature, wind speed, sunshine hour, humidity and rainfall, planting date of crops, soil type, and crops cultivation area, were collected from various sources. The climatic data were collected from the Meteorological, Climatological, and Geophysical Agency of Indonesia (BMKG) at Lombok International Airport, representing the river basin region. Information on irrigation, e.g., command area, crop type, cropping pattern, and rainfall...
data, was obtained from Balai Wilayah Sungai Nusa Tenggara I. The growing stages and Kc values were obtained from FAO.

2.5. Command areas and cropping pattern

The details of the crops relating to the cultivated area, crop types, and planting date applied for each growing period in the Dodokan watershed are presented in Table 1. The total irrigation command area covers approximately 11,087 hectares. Planting dates are divided into three growing seasons with different sowing starting dates. Crop types for each cropping pattern in the command area are paddy as a primary crop and secondary crops (maize and soybean).

3. Result and Discussion

Water requirement in the Dodokan watershed was estimated using the climate parameters for 1995-2016 and 2032-2040 in four scenarios. Irrigation water demand was estimated using the current climatic data for the present scenario: a) present scenario from 1995 to 2016; b) efficiency irrigation improvement in the present scenario; c) future scenario over the period between 2032 and 2040, and d) efficiency irrigation improvement in the future scenario.

The present scenario was run to determine the current irrigation demand and showed the amount of water saved if irrigation efficiency was improved in the watershed. Monthly averages of rainfall, humidity, wind speed, sunshine hours, and minimum and maximum temperature from 1995 to 2016 were applied to the CROPWAT model to calculate the demand in the first and second scenarios. In the future scenario, temperature and rainfall data from 2006 to 2014 were projected to a year from 2032 to 2040 and applied to the model to estimate irrigation water requirements in the climate change period. The increasing temperature in 2032-2040 was predicted to rise approximately 0.7 °C from the baseline period in 2006-2014. Meanwhile, rainfall was predicted to be raised 30% from the baseline. The predicted temperature and rainfall were applied to estimate water demand in the future period.
The reference evaporation (ETo) for the present scenario is presented in Figure 2. Figure 2 shows that the mean monthly ETo in the present scenario varies between 3.52 and 4.43 mm/day. In June mean monthly ETo was 3.52 mm/day as the lowest. In October, the highest ETo could be due to the high net radiation affected by temperature and humidity in that month. In the future scenario, ETo was predicted in the range of 4.47 mm/day as the highest in October and 3.47 mm/day in June as the lowest. In the future scenario, the mean annual ETo predicted 4.01 mm/day, increasing from 3.97 mm/day in the present scenario. The increasing mean annual ETo from the present scenario was predicted at approximately 0.8%. These results seem consistent with other research, which found that an increase in evapotranspiration was related to temperature and humidity [20, 23].
Figure 2. Mean monthly ETo comparison between period 2006-2014 and 2032-2040 as the function of net radiation in the corresponding month

Figure 3. Mean monthly effective rainfall comparison between period 2006-2014 and 2032-2040 as the function of total monthly rainfall in the corresponding month

The effective rainfall between 2032 and 2040 was predicted from historical rainfall data in 2006-2014. The significant effective rainfall in the future scenario was approximately 161.67 mm/month in December, whereas the lowest effective rainfall was approximately 3.47 mm/month in June. The total annual effective rainfall was calculated to be 1056.90 mm from 2032 to 2040. Meanwhile, the effective annual rainfall in the period 1995-2015 was predicted at 1010.39 mm. The increasing effective annual rainfall available for cropping was at the rate of 4.06%. The calculated and predicted effective monthly rainfall was then applied for both scenarios present and future as an input for water demand in the CROPWAT model. A comparison of effective annual rainfall for two different periods is shown in Figure 3.
Estimation of irrigation water requirement was applied in four scenarios condition. The highest monthly water demand in all scenarios was in November, with approximately 36.38 Mm³/month. Meanwhile, the annual irrigation demand in the future scenario was predicted to be 176.88 Mm³/year. The amount of water demand for irrigation was approximately 179.73 Mm³/year from 1995 to 2016. Therefore, the difference in water demand amount was approximately 1.61% between present and future scenarios. Improvement of irrigation efficiency up to 70% significantly affected irrigation water demand.
in the watershed. This effort would decrease the water demand from 179.73 Mm$^3$/year to 147,044.81 Mm$^3$/year in 2032-2040. Overall, these results indicate that climate change would increase irrigation water demand and improve irrigation efficiency as one effort would reduce the water demand.

4. Conclusions

This study predicted the impact of climate change on irrigation water demand in the cropland region in the Lombok river basin. The prediction investigates two scenarios: the present scenario in 1995-2016 and the future scenario in 2032-2040. The CROPWAT 8.0 model developed by FAO was applied in this study. This study predicted that ETo was in the range of 3.52 and 4.43 mm/day in the present scenario. This value was predicted to be in the range of 3.47-4.47 mm/day in the future scenario. Therefore, ETo was predicted to increase 0.80 % between the two scenarios. Over 2032-2040, irrigation water requirement was expected to increase by 1.61% to baseline. The predictions showed an increase of about 4.06% in the rate of effective annual rainfall in the future period. Furthermore, due to irrigation efficiency improvement up to 70%, irrigation water requirement was estimated to be approximately -18.18% in both scenarios, lower than without any improvement. The future study must consider the possibility of shifting the cropping pattern period to analyze the sensitivity of each parameter in irrigation water demand estimation.

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