Hydrological Water Balance Projection in Several Reservoir Catchment

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Abstract. According to data from Indonesian Agency for Meteorological, Climatological and Geophysics (Badan Meteorologi, Klimatologi, dan Geofisika or simply BMKG), Indonesia experienced changes in annual rainfall. Some areas of Indonesia experienced an increase in rainfall reaching 120 mm and other areas experienced decreasing. This condition certainly indicates a climate change will affect the availability of water around the location. The selection of the study location is the catchment area of the reservoir which has a large change in annual rainfall and the size of the reservoir and the benefits to the community. The analysis was carried out only by considering hydrometeorological parameters, rainfall and evapotranspiration. The projection data uses the CORDEX RCP 8.5 (2020-2045) and BMKG data (1999-2005). The results of the analysis show that the evapotranspiration value of the four catchment areas of the reservoir have a positive trend, with the highest increase in the Bili-bili catchment area in Maros reaching 4% in the rainy season and 3% in the dry season. This is influenced by the amount of sunshine duration above 10 hours. In contrast to evapotranspiration, the value of effective rainfall that occurs in the four catchment has a negative trend although it is not very significant. During the dry season, all location predicted there will be no runoff and no infiltration.

1. Introduction

In the map of changes in annual rainfall for the period 1991-2010 to the period 1971-1990 from the BMKG Indonesia, several large dams spread across Indonesia have significant changes in annual rainfall. The map shows that Papua Island and parts of Kalimantan Island have experienced a decrease in rainfall which is classified as high, reaching 120 mm. Meanwhile, the southern region of Sulawesi Island and several areas on the islands of Sumatra and Java experienced an increase in annual rainfall of between 40 mm to 80 mm. The trend of changing rain patterns in the world in general experiences varied changes in each geographical area. [1]

West Africa geographically stretches from an area with dry climatic conditions in the north to a humid tropical climate in the south.[2] using data from 30 regional models of CORDEX simulations in

12 catchments in the West African region, the results of temperature projections in 2046-2065 show that the highest temperature increase pattern is in the dry northern region. For the northwestern part, where the temperature increase is quite significant, there is a projected decrease in rainfall which results in a drastic decrease in surface water runoff by up to 15%. On the other hand, what happened in the southwest area.

In this study, an analysis was carried out to determine regional trends in the hydrological water balance that might occur in 2020-2045 due to the influence of climate change. The selection of the study location is the catchment area of the reservoir which has a large change in annual rainfall and the size of the reservoir and the benefits to the lives of the surrounding community.

Water balance analysis only considers hydrometeorological parameters (rainfall and evapotranspiration). The water balance does not consider runoff, infiltration and groundwater parameters.

1. 1. Study Area

1.1.1.Riam Kanan catchment area (Banjarbaru). Riam Kanan Reservoir is the largest reservoir in South Kalimantan. Geographically, the Riam Kanan reservoir is located at 115º0'30" East Longitude, 3º31'2" South Latitude. With a catchment area of 1,043 km^2, this reservoir is able to accommodate up to a volume of 1,200 million m^3 and a flood water level of 9,200 hectares. Riam Kanan Reservoir is intended as a power plant, providing raw water for irrigation needs on 30,000 hectares of agricultural land.

1.1.2. Bili-bili catchment area (Maros). The damming capacity of the Bili-bili Dam is 375 million m^3 with an effective reservoir of 346 million m^3 which is used to prevent the overflow of the Jenebareng River which often causes several surrounding areas to be flooded. With a catchment area of 385 km^2, the reservoir is also used as a fulfillment of irrigation water for 2360 hectares as well as a source for drinking water management, aquaculture, power plants and tourist areas.

1.1.3.Batu Tegi catchment area (Lampung). Batu Tegi Dam has a water capacity of 690 million m^3 which is used for irrigation of 66,573 hectares in North Lampung, Central Lampung, East Lampung, South Lampung and Metro City Regencies. In addition, for hydropower plants with an installed capacity of 2 x 14 Megawatts, supply of raw water for clean water for the cities of Bandar Lampung, Branti and Metro of 2,250 l/s, flood control, fisheries and tourism.

1.1.4.Saguling catchment area (Bandung). The geographical location of the Saguling dam is at 107º22'7" East Longitude, 6º54'50" South Latitude, which is included in the West Bandung Regency, West Java. Having a catchment area of 2,283 km^2, the Saguling dam can accommodate up to 970 million m^3 of volume when the water level is flooded. The annual regional rainfall in 2007-2014 varied from 1337 to 2970 mm and the average monthly evapotranspiration was 1153 mm. [3]

2. Materials and method

2. 1. Observation data

BMKG observation climate data is used to analyze climate trends in the last 22 years, from 1999 to 2020, then extrapolation is carried out as projected data for 2020-2045.Climate data used in the form of air humidity data, duration of sunlight and wind speed as well as topographic data at the stations under review. Data were obtained from observation stations located around the study area:

Table 1. Observation station**.**

No.	Station name	Latitude	Longitude	Altitude
1	Stasiun Meteorologi Syamsudin Noor	-3º26'31"	114º45'14"	32
2	Stasiun Geofisika Bandung	-6º54'1"	107º35'50"	791
3	Stasiun Meteorologi Radin Inten II	-5º9'36"	105º6'36"	85
4	Stasiun Klimatologi Maros	-4º55'51"	119º34'19"	13

2. 2. *Model data*

The model data used daily rainfall data from CORDEX which is a scale reduction from the ensemble of four global models using RCM (Regional Climate Model) RegCM4 with scenarios RCP 4.5 and RCP 8.5. This scenario is considered because it is able to represent daily concentration conditions because it covers a complete range of concentrations. [4]

Table 2. GCMs used in the study area.

No.	GCMs	Developer	Resolution
1	CRNM-CM5	Centre National de Recherches Meteorologiques, France	1.40625° × 1.40625°
2	CSIRO-Mk-3-6-0	Commonwealth Scientific and Industrial Research Org.	1.875° × 1.875°
3	EC-EARTH	The European wide consortium	1.125° × 1.125°
4	MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	1.875° × 1.875°

The model data was then corrected for bias according to the availability of historical CORDEX data and observational data, in the period 1999-2005 for the Bili-bili catchment area and 1990-2005 for the other three areas. The bias correction was used using empirical Quantile Mapping (eQM) method. There are three steps to correcting bias using the quantitative mapping method. First, the predicted and actual data are identified for each distribution so that the probability density function (PDF) is obtained. Second, the PDFs are integrated to obtain the respective distribution functions (CDF). Third, the quantile value of each CDF is taken and a transfer function is formed, y = (x) where x and y are the quantiles of the predicted and actual data, respectively. [5]

2. 3. *Forecast data*

To project the value, this study uses a linear regression method to determine the value trend of the water balance variable, as well as the ARIMA (AutoRegressive Integrated Moving Average) method to predict the evapotranspiration value which will be used for water balance analysis. The rationale in the time series is the current observation (Z_t) which is influenced by one or more previous observations (Z_{t-k}). [6]

Consider the general ARIM (p,d,q) model

$$\varphi(B)(1-B)^{d}Z_t = \theta(B)a_t \tag{1}$$

Where $\varphi(B) = (1- \varphi_1 B - \dots - \varphi_p B^p)$, $\theta(B) = (1-\theta_1 B - \dots - \theta_q B^q)$, and the series α_t is Gaussian N (0, σ_α^2) white noise process. The deterministic trend parameter θ_0 is omitted for simplicity but no loss of generality. [7]

2. 4. *Change of Hydrological water balance*

Rainfall data and evapotranspiration data in the same period are then calculated to determine the difference value (R-ETo). This difference in value can be an indicator of the availability of surface water runoff in a catchment area experiencing an increase or decrease due to the impact of climate change.

In forecasting conditions, the data being compared is the CORDEX ensemble projection rainfall data with projected evapotranspiration data. This ETo projection was obtained from BMKG observation data which was calculated using the Penman-Monteith FAO 56 method, then projected using the ARIMA method and linear regression.

The Penman-Monteith FAO 56 method is the recommended standard method, because it can predict ETo with a high probability in various locations and climates and has the possibility to be applied to short data conditions. [8]

3. Result and discussion

3. 1. *Model Calibration*

The CORDEX data is focused on historical rainfall data in one of the research areas, Banjarbaru, compared with observation data from the Syamsudin Noor Meteorological Station, BMKG plotted on Figure 1. Rainfall data is monthly mean data in the range from 1999 to 2005. There is a mismatch under certain conditions. In rainy conditions below 15 mm, CORDEX overestimates. Meanwhile, for rain conditions above 20 mm, CORDEX estimates it too low. The difference between observation data and model data can be influenced by several factors, including the simulated model data and the condition of the observation data. All models correspond to the direction of temperature change, results between models can vary widely and each model has inherent biases. The difference in results is due to the difference between the resolution of each GCM model, model formulation and model parameterization. [1] The coefficient of determination for corrected CORDEX data in Banjarbaru, Bandung, Maros and Lampung were 0.94, 0.98, 0.96 and 0.97 indicating that the model data almost matched the actual data. However, for the probability below 5%, the corrected data seems to cut at a certain value. This needs to be done to check the coefficients.

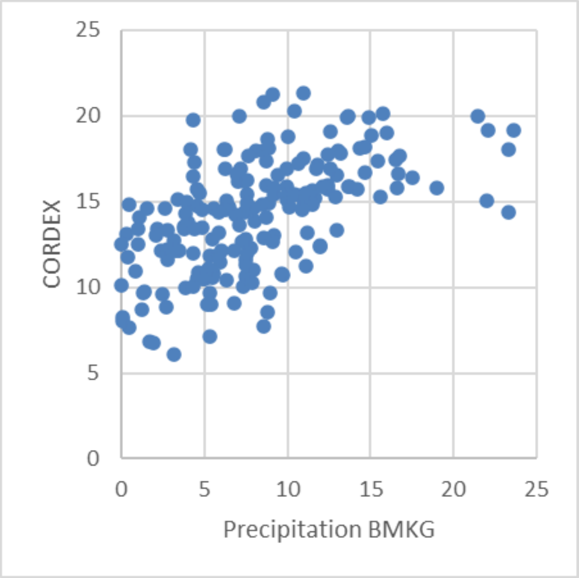

Figure 1. Comparison BMKG data to CORDEX.

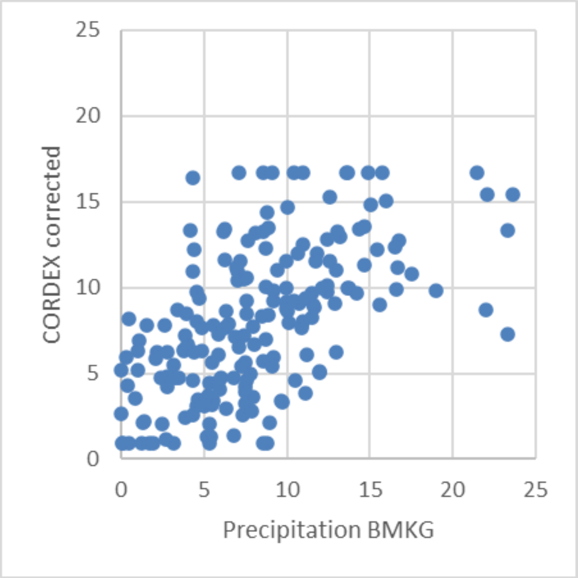

Figure 2. Comparison BMKG data to corrected CORDEX.

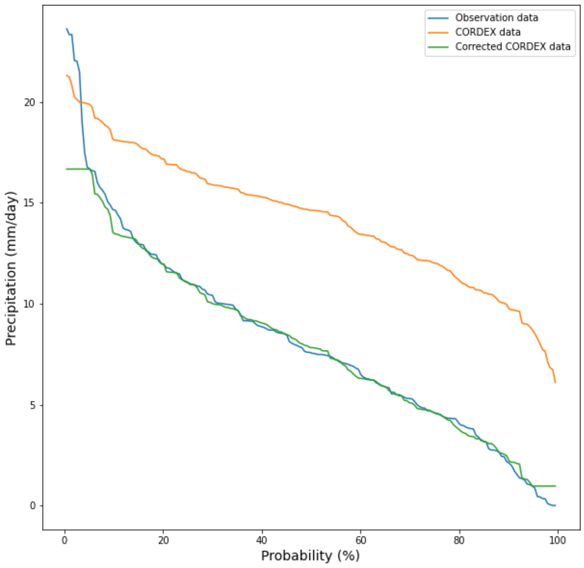

Figure 3. Probability curve of precipitation in Banjarbaru (1990-2005).

3. 2. Evapotranspiration

In the BMKG climate data, before calculating the evapotranspiration value, blank data will be checked. Furthermore, the blank filled with the average seasonal value for each variable and location. The results of daily evapotranspiration calculations which are then calculated monthly averages are shown in Figure 4. The highest evapotranspiration is in the Maros region in South Sulawesi. The high duration of radiation and the average temperature recorded at the Maros Climatology Station affect the rate of evapotranspiration.

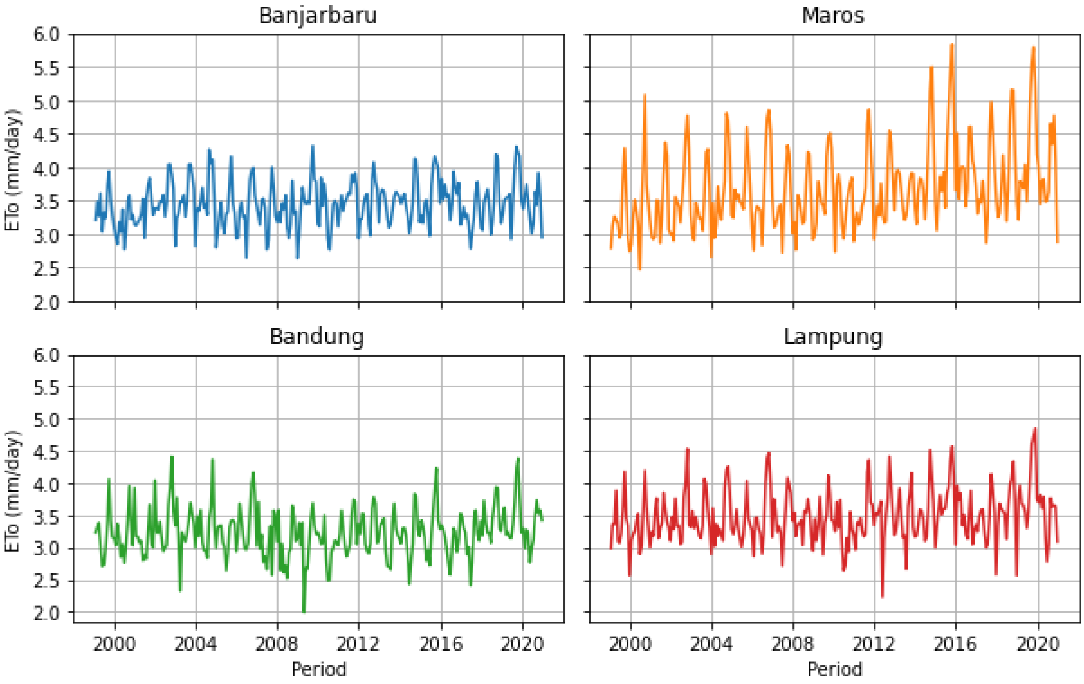

Figure 4. Monthly mean evapotranspiration.

3.2.1 Forecast using ARIMA. The first step in ARIMA modeling is data identification, distribution pattern of evapotranspiration data in the entire catchment area. In Banjarbaru and other areas it forms a normal curve pattern. Furthermore, the stationary data test was carried out using the Augmented Dickey-Fuller Test (ADF test) with the p value indicator must be less than 0.05 so that the data could be modeled without differentiation.

Table 3. Result of ADF test.

Catchment area	ADF statistic	p value
Saguling (Bandung)	-3,159	0,022
Riam Kanan (Banjarbaru)	-4,574	0,000
Batu Tegi (Lampung)	-4,172	0,000
Bili-bili (Maros)	-2,941	0,041

The next process is the identification of the ARIMA model by determining the order of p, d and q for each data obtained through the smallest Akaike information criterion (AIC) value. In the process of determining the AIC value, you must also enter the maximum order of p and q obtained by looking at the Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) in the plotting of each catchment area. Most of the catchment areas have a maximum q-order of 2. For the p-order in the Maros and Lampung catchments, the maximum p is 3 and the Bandung and Banjarbaru areas have a maximum p of 2.

After obtaining the order of p, d and q, the next step is to make predictions or forecasts with ARIMA according to the order of each data in the catchment area. The order in each region is generated by auto arima which has determined the maximum order in the previous stage.

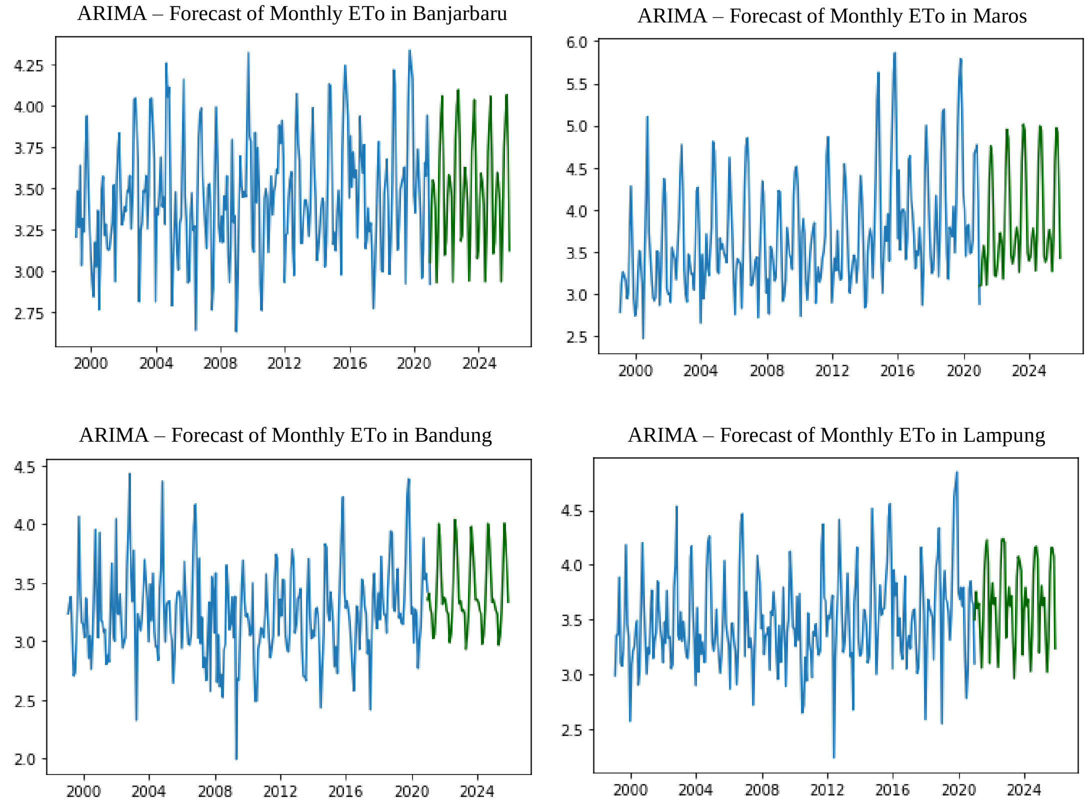

Figure 5. ARIMA forecast of evapotranspiration.

The results of the projection of monthly evapotranspiration values in the four catchments are found in Figure 5. It shows the prediction using ARIMA has a very small upward or downward trend, and the projection data looks typical. In the Maros area, the projection appears to have a slight upward trend, according to the linear regression which has the highest slope. This is different from the catchment area of Lampung, which has decreased from 2023. This projected value does not show an extreme value. If the prediction is extended, it will produce the same value close to the average. Therefore, the amount of predictive data is only made up of 60 steps or 60 months.

3.2.1 Forecast using Linear Regression. The trend of increasing annual evapotranspiration is found in almost all catchments. In Banjarbaru annual evapotranspiration increased by 0.14 mm over 22 years, or with a slope of less than 1%. This condition is in accordance with previous research in the Riam Kanan catchment area, Banjarbaru [9] which showed that the evapotranspiration value in the 1983-2017 period experienced an increasing trend of only about 0.01 mm.

Annual evapotranspiration in Maros has a significant upward trend reaching 3.3%, several factors that influence, among others, the wind speed that occurs in Maros has increased to 0.5 m/s in contrast to the other three locations which have decreased. And the length of annual irradiation in Maros which has the steepest upward trend.

3. 3. Hydrological water balance

Water balance in catchment could be an indicator of water surface availability, whether it is a surplus or deficit. The effective rainfall in the dry season in Figure 7 shows that the Banjarbaru catchment area is experiencing a negative trend while the other three areas are experiencing an increase. The calculation of effective rainfall is carried out with BMKG observation rainfall data.

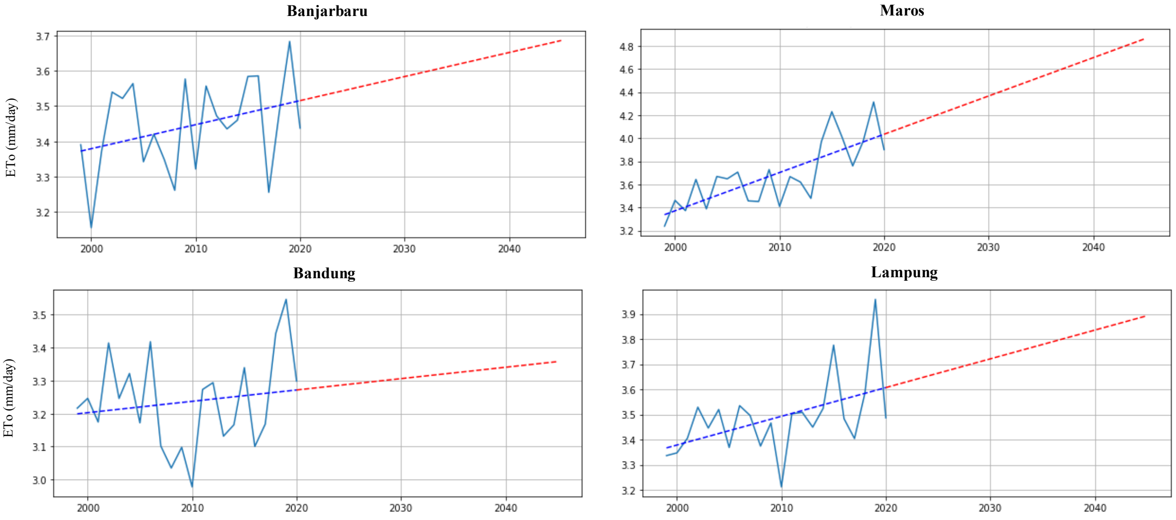

Figure 6. Forecast of evapotranspiration using Linear regression method.

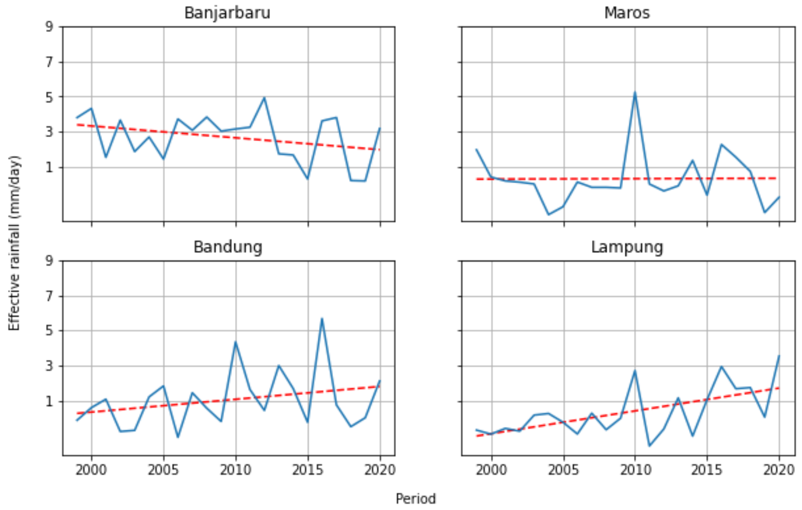

Figure 7. Effective rainfall in dry season**.**

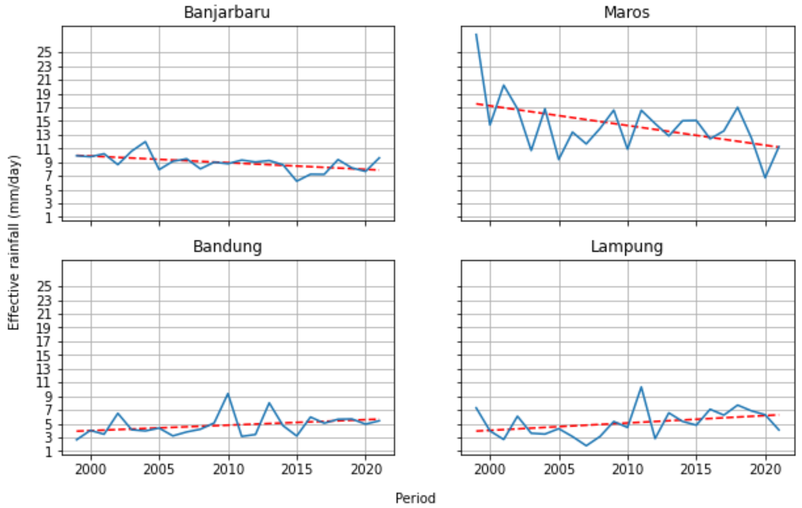

Figure 8. Effective rainfall in wet season.

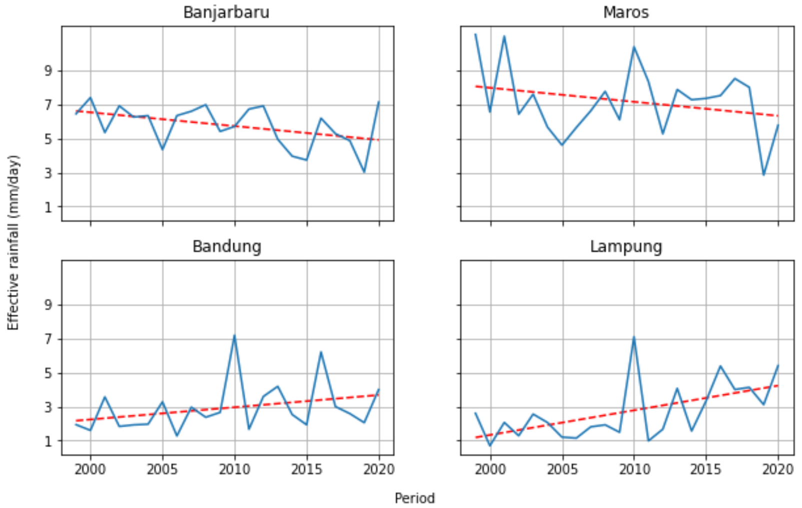

Figure 9. Annual average of effective rainfall.

3.3.1. Projected hydrological water balance. In order to determining the projected effective rainfall value for each catchment area, the difference between the corrected CORDEX rainfall data and the projected evapotranspiration value should be calculate. In the catchment area of the Maros reservoir in the rainy season, the effective rainfall will experience an extreme decline in 2045 with a steep downward trend reaching 6 mm in 26 years. In the catchment areas of Banjarbaru and Lampung, the decrease in effective rainfall in 26 years is only about 7%, while in Bandung there is almost no significant trend. This can be caused by the high slope of the increase in the value of evapotranspiration in the Maros area which causes a high slope of decreasing effective rainfall.

In contrast to the rainy season, in the dry season the entire catchment area has a downward trend, except for the Banjarbaru area where the effective rainfall increases by about 2%. The entire catchment area has a negative effective rainfall. This can be an indicator of the absence of water runoff or infiltration that occurs in the entire catchment area.

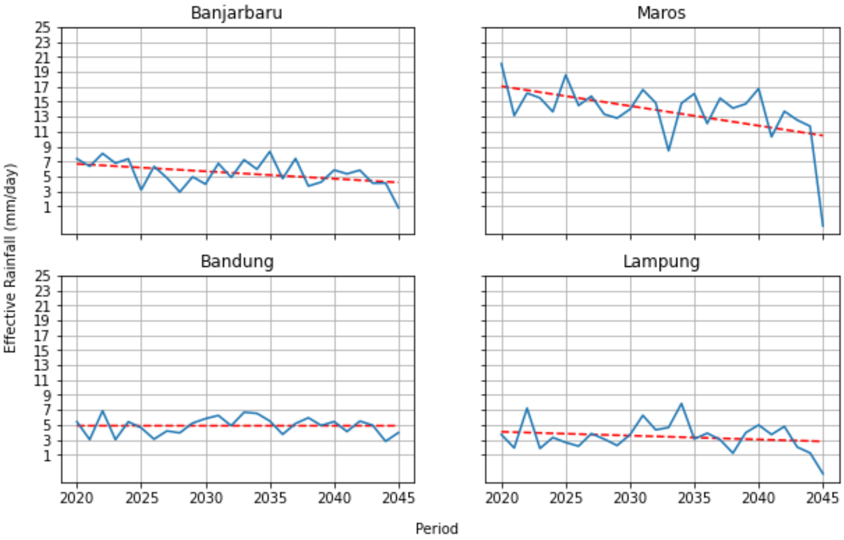

Figure 10. Projected water balance in wet season.

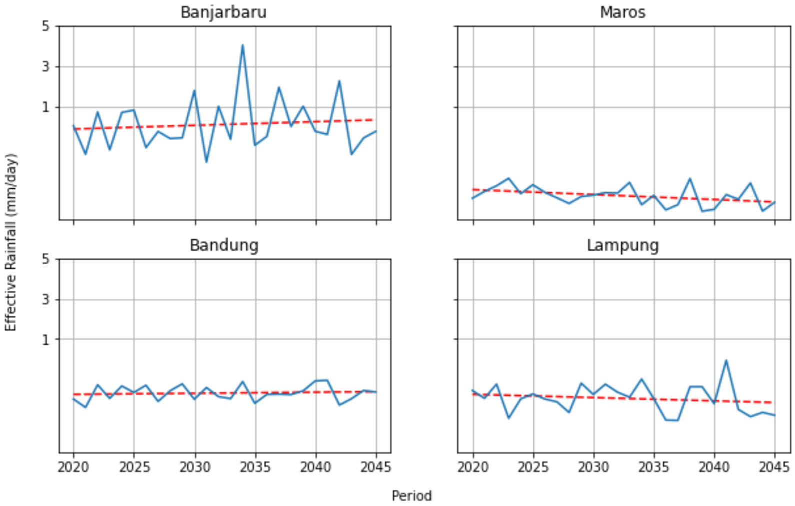

Figure 11. Projected effective rainfall in dry season.

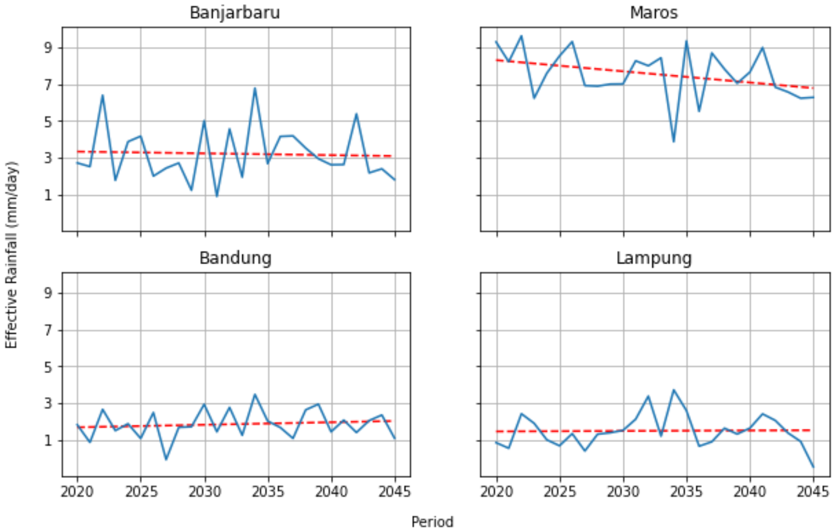

Figure 12. Annual average projected effective rainfall**.**

4. Conclusion

The CORDEX projected climate data has a different sensitivity for each amount of rain. For rain above 10mm CORDEX has a higher forecast, while for some extreme rains it is expected to be lower. The value of evapotranspiration in all catchments each year has increased significantly, the largest reaching 3.3% in the Bili-bili catchment area in Maros which has the largest trend of increasing evapotranspiration values in several classification periods. This condition is much influenced by the high wind speed and the length of the sun irradiation. In the catchment area of Saguling Bandung, it is indicated to have a good hydrological water balance projection, because in two seasons there is no effective decrease in rainfall. Almost all of the catchment areas in the dry season for the 2020-2045 period are predicted have no runoff or infiltration. Projected data using the ARIMA method on monthly evapotranspiration data do not show a significant upward trend, some will return to the mean value if they reach a certain amount of projected data. Meanwhile, for seasonal and annual data which has a shorter amount of data, the upward or downward trend will be very extreme.

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