Analysis of variability and projection of extreme rainfall in West Java

R C H Hutauruk\(^1\), T Amin\(^2\) and A M Irawan\(^3\)

\(^1\) Global Atmosphere Watch Palu Station, Indonesia Agency for Meteorology Climatology and Geophysics (BMKG)
\(^2\) Center for Applied Climate Information and Services, Indonesia Agency for Meteorology Climatology and Geophysics (BMKG)
\(^3\) Department of Climatology, School of Meteorology Climatology and Geophysics (STMKG)

*e-mail: rheinhart.christian@gmail.com

Abstract. This research discusses the effect of climate change on extreme rainfall in West Java using the RCP 4.5 and RCP 8.5 scenarios by comparing daily rainfall data with model ACCESS-1, CSIROMK3.6 model, MIROC-5 from NASA Earth Exchange Global Daily Downscaled Projection (NEX-GDDP) and the ensemble of three models each season with Extreme Dependency Score (EDS) method. This study projects an extreme rainfall index of 30 years (2011-2040). The three extreme rainfall indices issued by the Expert Detection Team and the Climate Change Index (ETCCDI) consisted of Rx1day, R50mm, and R95p used in this study. The results showed that the projection period (2011-2040) used RCP 8.5 which had a trend of increasing extreme rain index that was greater than RCP 4.5. For RCP 8.5 the maximum rainfall will increase in Indramayu, Majalengka, Purwakarta, Sukabumi and Ciamis areas. Increased rainy days occurred in Bogor, Bekasi, Karawang, Purwakarta, Bandung, Sumedang, Majalengka, Cirebon, Indramayu. Extreme rainfall will increase in Bekasi, Karawang and Bogor regions.

1. Introduction

Climate change is the impact of global warming. Global warming does not occur directly but gradually, this phenomenon trigger by Greenhouse Gases (GHG), which significantly increases carbon dioxide gas (CO\(_2\)) which is the leading cause of the greenhouse effect resulting in global warming [1]. The temperature increase had occurred during the new industrial revolution starting in 1850. At that time, the concentration of carbon dioxide (CO\(_2\)) in the atmosphere was around 290 ppmv until now, it reached about 350 ppmv [1]. The Industrial Revolution using coal in industry, excessive GHG generated from the industrial era until now, will accelerate the global warming process, impacting several increasing threats such as increased surface temperature, increased mean sea level, extreme weather, and increased air pollutants [2]. Furthermore, there will be more areas where high rainfall incidence is rising while in some places it is decreasing [3]. Climate projection can minimize the impact of climate change in the future if mitigation is carried out on extreme climate.

Rainfall is a climate parameter that is very influential in every activity of human life. Extreme rainfall has negative impacts then the analysis is needed to study these events [4]. Understanding changes in extreme rainfall events is critical in many applied studies because of their enormous and disproportionate impact on people and ecosystems compared to mean rainfall changes [5]. Studies on a global scale show that rainfall changes are generally consistent with a wet climate [6]. Changes in spatial patterns in
extreme rainfall are not uniform because only several stations have a significant increase in extreme rainfall [8]. Several factors cause the risk of flooding and landslides in an event area with extreme rainfall events and rainfall frequency. In the case of flooding, what happens is that the amount of rain per rainy day increases [2].

IPCC (Intergovernmental Panel on Climate Change) has created several climate scenarios based on greenhouse gas concentrations known as Representative Concentration Pathways (RCP). In this study using RCP 4.5 and RCP 8.5, it should be noted that RCP 4.5 is an intermediate emission developed by the Pacific Northwest National Laboratory. Then, for the advantages of the RCP 4.5 scenario, there is a policy to limit greenhouse gas emissions through the Kyoto Protocol [9]. Whereas RCP 8.5 is an emission scenario without policies to reduce emissions with a rapid increase in methane, high use of fossil fuels, and the slow development of technology to reduce the impact of climate change. According to the IPCC [3] high latitudes and the equatorial Pacific are likely to increase mean annual rainfall under the RCP 8.5 scenario. In arid regions of middle and subtropical latitudes, the average rainfall is expected to decrease. In contrast, in many wet areas in the middle latitudes, the average rainfall is likely to increase below the RCP 8.5.

In previous research [7] intensity and probability of extreme rainfall in Indonesia in 2011-2035 using three data models, namely ACCESS-1, EC-EARTH, and MIROC-5 using the Generalized Extreme Value (GEV) parameter, as well as regional changes and the probability of extreme events are analyzed using cluster analysis and Probability Density Function (PDF). The projection results show an increasing chance of extreme rainfall with high intensity. The results of the cluster and PDF projections also result in the possibility of high extreme rainfall being more widespread.

Based on this description, we will study the projections of extreme rainfall in West Java. Also, this study will compare the CSIRO-MK3.6, MIROC-5, ACCESS-1, and ensemble models from the three models using the Extreme Dependency Score (EDS) analysis. The best model will be used as a projection model for analyzing the extreme rainfall trend in 2011-2040.

2. Data and Methods

2.1. Datasets
This study utilizes the daily rainfall record in 21 observation stations in the West Java area (Figure 1). To assess the climate analysis, long-term data is used with 30 years (1981-2010). Simple quality control processing had been carried out to make sure the availability of the data. From those 21 stations, all the recorded datasets had good quality with the missing data were <10%. The climate projection for extreme events was also estimated using several data models CSIRO-MK3.6, MIROC5, and ACCESS1 from Nasa Earth Exchange Global Daily Downscaled Projections (NEX-GDDP).
The extreme index of rainfall intensity and frequency has been considered to analyze the extreme event in the future projection. In this study, the ETCCDI extreme rainfall index was used to detect changes in rainfall over historical and projected periods. An essential indicator to identify extreme events in the study area is presented in Table 1.

Table 1. The climate change index used in this study

| Index   | Definition                                             | Unit  |
|---------|--------------------------------------------------------|-------|
| RX1day  | Sub-seasonal maximum 1-day precipitation               | mm    |
| R50mm   | Sub-seasonal count of days when precipitation ≥ 50mm/day | day   |
| R95p    | Sub-seasonal total precipitation when >95th percentile  | mm    |

2.2. Methods

To identify each index's temporal trend in the 1981-2010 period for all stations, slope analysis is done by using Least Square method, which is performed by RClimdex application. The selected index will be used as the main indicator for the extreme event projection. Furthermore, the confidence level test for the trend was carried out using the Mann-Kendall test. In this study, p-value of those three indices are used to see the major significant trend of West Java area.

Several datasets from multi-model climate projections were carried out in this study. Root Mean Square Error (RMSE) validation of training data as a consideration of the weight value of each model. The weighted value varies according to the contribution of each model to the prediction skill. Small RMSE value in the training data indicates that the model has a small error rate and better predictive ability. When the RMSE value had been identified, then the weighting is carried out according to this equation expressed as:

\[
\omega_i = \frac{1}{\sigma^2}
\]  

where \(\omega_i\) is model weight and \(\sigma\) is RMSE of each model. Then ensemble means of each projection model weighted based on the RMSE value of training data validation, which is expressed as:
\[ Y'_{\text{wav}} = \frac{\sum \omega_i Y_i'}{\sum \omega_i} \quad (2) \]

The best model for projection is determined by using EDS. The EDS method uses dichotomy prediction (yes / no): dichotomy prediction (yes / no) is a prediction that divides into two possibilities (yes or no), for example; rain-no rain, extreme-no extreme, these events are summarized in the form of a contingency table. Contingency tables (Table 2) are composite distributions of prediction and observation precipitation [10]. A threshold for the extreme category was defined as precipitation greater than or equal to 50 mm. After the values of H, F, M, and C were obtained, then the EDS value is searched using the formula:

\[ EDS = \frac{\log p - \log T}{\log p + \log T} \quad (3) \]

where \( p = (H+M) / n \) and \( T = H / (H+M) \). The EDS value ranges from -1 to 1, if the EDS value is positive, it means that the data on the extreme rainfall events of the observation and the model have agreement. The best value here is used which is close to 1 or the positive direction, negative values indicate that there are many misses in the model and observations [11].

**Table 2.** Contingency table where hits (H) are the number of rainfall events in the model and observations when it was above 50 mm, false alarm (F) shows the number of rainfall events in the model fit the threshold but the observation is not (observation <50 mm), misses (M) shows the number of occurrences on observations fit the threshold but the model is not (model <50 mm), correct rejection (C) is the number of observations and the model is below the threshold.

|                | Observation (yes) | Observation (no) | Total   |
|----------------|-------------------|------------------|---------|
| Model (yes)    | Hits (H)          | False alarm (F)  | H+F     |
| Model (no)     | Misses (M)        | Correct rejection (C) | M+C   |
| Total          | H+M               | F+C              | n = H+F+M+C |
3. Result and Discussion

![Spatial distribution of Rx1day index 1981-2010](image)

**Figure 2.** The spatial distribution of the Rx1day index 1981-2010, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) is indicated by a coloured triangle.

In this study, we divided the seasons into four sub-seasons consisting of December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON). In the four sub-seasons, it can be seen that in Fig. 2, there is a decreasing trend in the maximum amount of one-day rainfall per sub-season (Rx1day) in the eastern to southeastern parts of West Java. Most of the central to western parts of West Java experienced an increasing trend (Rx1day). In the dry season (JJA), it can be seen that almost all areas of West Java experience a decreasing trend of 0-5 mm every 30 years. In the DJF Cirebon and Cianjur sub-season it experienced a decrease of 5-10 mm every 30 years, then Subang and Tasikmalaya experienced a decrease of 2-5 mm every 30 years, the decline in these areas had a level of confidence (p-value ≤ 0.05) this means that a decreasing trend occurred significantly and indicates that the maximum rainfall incidence in one day is decreasing.
Figure 3. The spatial distribution of the R50mm index 1981-2010, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) is indicated by a coloured triangle.

The increasing and decreasing trends in the Fig.3 and Fig.2 indices has a pattern similar to the increasing trend in the eastern part of West Java and then the decline occurring in the western part of West Java. For the index of the number of days with rainfall ≥ 50 mm (R50mm) per sub season, it can be seen that in the eastern part of West Java (Cirebon, Ciamis, and Tasikmalaya) there are several significant trends (p-value ≤ 0.05) down with a value of 0-2 every 30 years means that the number of days with rainfall ≥ 50 mm will decrease. An increasing trend dominates the central to the eastern part of West Java, a significant upward trend is found in the Bandung and Bogor areas with an increase of 0-2 days every 30 years, meaning that the number of rainy days ≥ 50 mm will increase. The dry season (JJA) is dominated by a decreasing trend (R50mm) but not significant.
Figure 4. Spatial distribution of the R95p index 1981-2010, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) is indicated by a coloured triangle.

In Fig. 4 the R95p index is the total amount of annual sub-season rainfall with rainfall above the 95th percentile. The pattern of the R95p index also has the same pattern as the other two indices, namely that a decreasing trend dominates East West Java and an upward trend dominates the western part. However, from Fig. 4 it can be analyzed if the R95p index experienced a more significant pattern of decline in the southeastern part of West Java. In the rainy season (DJF), there is a significant decrease in the R95p index, namely Cianjur (-9.291), Cirebon (-8.474), and Tasikmalaya (-6.389) which means there is a decrease in rainfall with a value of 5-10 mm every 30 years. The negative trend in the R95p index indicates that the incidence of rain with a very wet nature decreases during the rainy season. In the transition season to the rainy season (SON), it can be seen that a decrease in the R95p index dominates West Java. In the MAM sub-season in Indramayu (northeast), there is a significant increase in trend with a value of 2,126 mm every 30 years.
3.1. Spatial Distribution of Extreme Dependency Score (EDS) for each models

![Image of spatial distribution](image_url)

**Figure 5.** EDS value of each model.

The criteria for extreme rain used for the contingency table are rainfall of more than 50 mm between the observation and rainfall data of the ACCESS-1 model, CSIROMK3.6, MIROC-5, and ensemble models of the three models. The positive value in the table above shows the extreme similarity between the observation and the model, a positive value means that there is an extreme event in the observation and model. The closer to positive 1, the more similar the extreme patterns of observation and models are. If the value is negative, the extreme events in the observation are not found in the model.

In Fig.5, you can see the EDS value of each rain post, for the ACCESS-1 model there is a circle which indicates that the strong negative EDS value (orange and red colour) consists of 5, then in the CSIROMK3.6 model there is 1, the MIROC-5 model has 7, and the ensemble has 8. By looking at the number of circles in the model that has the most EDS values close to +1 (green to blue), it can be concluded that the CSIROMK3.6 model is the best compared to the ACCESS-1, MIROC-5, and ensemble.
3.2. Spatial Distribution Extreme Indices for RCP4.5

**Figure 6.** The spatial distribution of RCP 4.5 index Rx1day 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

For projections using RCP 4.5 in each sub-season Fig. 6, it can be seen that the entire West Java region has no significant change. Increasing and decreasing the Rx1day index in West Java using RCP 4.5 has not experienced a significant increase or decrease, this is related to RCP 4.5, it is explained that there are efforts to adapt and mitigate climate change. In the rainy season (DJF), it can be seen that there is a decrease in the Rx1day index trend ranging from 0-2 mm every 30 years, then in the transitional dry season (MAM), there is an increase in the maximum rainfall in one day (Rx1day) which means high rainfall in the MAM sub-season. when entering the dry season it will increase.
Figure 7. The spatial distribution of RCP 4.5 index R50mm 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

For the index of extreme rainy days ≥ 50 mm in each sub-season Fig. 7, the increase and decrease in rainy days is not too severe, only around 0-2 days every 30 years. In the DJF sub-season for the 2011-2040 period, it can be seen that the eastern part of West Java has an increase in rainy days and the western part of West Java there is a decrease in rainy days in West Java. Compared with the historical period 1981-2010, there is a difference, namely an increase occurred in the east of West Java and a decrease in the R50mm trend occurred in the western part. The transitional dry season (MAM) has a pattern of an increasing trend, which is the same as the index Rx1day, which means an increase will increase in rainy days in the frequency of rainfall. In the JJA sub-season, an upward trend can be seen in the north of West Java and a decreasing trend in the southern part of West Java. There is no significant increase or decrease in the R50mm trend because the p-value of the trend index is greater than 0.05.
Figure 8. The spatial distribution of RCP 4.5 index R95p 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

In the projection period Fig.8, the total rainfall index is above the 95th percentile (R95p), from the data set, it is found that in each sub-season there is only an increase and decrease in a trend of 0-2 mm every 30 years. In the rainy season (DFJ), it can be seen that the northern part of West Java has an increase in the R95p index and the south of West Java there is a decrease, this indicates that the incidence of rain with a very wet nature will increase in the north of West Java and decrease in the south of West Java as well as in the sub season dry (JJA). In the transitional dry season (MAM), it is clear that there is an increase in the R95p index in all of West Java except for the Tasikmalaya area. The increase and decrease in the R95p index in each sub-season are not significant, meaning no change in the 95th percentile rainfall in the 2011-2040 period.
3.3. Spatial Distribution Extreme Indices for RCP8.5

![Figure 9](image.png)

**Figure 9.** The spatial distribution of RCP 8.5 index Rx1day 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

In Fig.9 the Rx1day index projection using RCP 8.5 shows a significant increase in the index trend, in contrast to RCP4.5 which projects an index trend but nothing is significant. During the rainy season (DJF), it can be seen that there is an increase in the trend index, the areas where the trend is increasing are Indramayu, Cirebon, Kuningan, and Purwakarta with a value of 0-2 mm every 30 years. Increasing the trend of the Rx1day index in a significant area has the risk of increasing the maximum rainfall and impacting the occurrence of floods and landslides in these areas. The seasonal switching pattern is almost the same as RCP 4.5 in MAM, up and down in SON.
Figure 10. The spatial distribution of RCP 8.5 index R50mm 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing decreasing indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

In Fig. 10 shows that the increase in extreme rainy days (≥ 50 mm) in the DJF sub-season has increased in the north of West Java and decreased in the south of West Java with a value of 0-2 days every 30 years. The areas of Indramayu, Cirebon, Majalengka, and Subang in the DJF sub-season experienced significant changes (p-value ≤ 0.05) for rainy days. In the transitional dry season (MAM) there is a significant increase of 0-2 days every 30 years in almost all of West Java, meaning that when it is about to enter the dry season (JJA) there will be an increase in rainy days with rainfall ≥ 50 mm. In the JJA sub-season using RCP 8.5, there was an increase in the R50mm index trend with a value of 0-2 days, but the increase was not significant. Interestingly, in each transitional sub-season, there is a significant change in the overall trend index in the West Java region.
Figure 11. The spatial distribution of RCP 8.5 index R95p 2011-2040, a triangle pointing upwards indicates an increasing trend, a triangle pointing downwards indicates a decreasing trend. Significant trend changes (p-value ≤ 0.05) are indicated by coloured triangles.

In the 2011-2040 projection period for the R95p index Fig. 11, there was an increase in extreme rainfall in the DJF and MAM sub-seasons, decreasing the JJA and SON sub-seasons. A significant increase occurred in the MAM sub-season, namely in the Bekasi, Bogor, and Sukabumi areas with a value of 0-5 mm every 30 years. This significant increase in trend occurs in the MAM sub-season which is a transitional month of the dry season, this means that when the dry season enters the extreme rainfall will increase. In the transition to the rainy season (SON), it can be seen that there is a decrease in extreme rainfall throughout West Java, meaning that when it is about to enter the rainy season (DJF) the rainfall will fall with a value of 0-5 mm every 30 years. When compared with RCP 4.5, the increase and decrease in the extreme rain index, which is large and significant, is mostly found in RCP 8.5.

4. Conclusions

Based on the research results, the conclusions obtained are as follows, the extreme rain trend index in West Java for the period 1981-2010 for maximum rainfall (Rx1day) will increase in the Indramayu and Bogor areas. The increase in rainy days (R50mm) occurred in the areas of Bandung, Bogor, and Indramayu. Extreme rainfall (R95p) will increase in the Indramayu and Bogor areas. Many positive EDS values are found in the CSIRO-MK3.6 model so that the CSIRO-MK3.6 model is the best model of the ACCESS-1, MIROC-5, and Ensemble models of the three models. For the projection period (2011-2040) using RCP 8.5 has a significant increasing trend in extreme rain index which is more than RCP 4.5. For RCP 8.5, the maximum rainfall (Rx1day) will increase in the areas of Indramayu, Majalengka, Purwakarta, Sukabumi and Ciamis. The increase in rainy days (R50mm) occurred in the areas of Bogor, Bekasi, Karawang, Purwakarta, Bandung, Sumedang, Majalengka, Cirebon, Indramayu. Extreme rainfall (R95p) will increase in the Bekasi, Karawang, and Bogor areas.
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