Simulation and prediction the impact of climate change into water resources in Bengawan Solo watershed based on CCAM (Conformal Cubic Atmospheric Model) data

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Abstract. Bengawan Solo Watershed is one of the largest watersheds in Indonesia. This watershed flows in many areas both in Central Java and East Java. Therefore, the water resources condition greatly affects many people. This research will be conducted on prediction of climate change effect on water resources condition in terms of rainfall conditions in Bengawan Solo River Basin. The goal of this research is to know and predict the climate change impact on water resources based on CCAM (Conformal Cubic Atmosphere Model) with downscaling baseline (historical) model data from 1949 to 2005 and RCP 4.5 from 2006 to 2069. The modeling data was validated with in-situ data (measurement data). To analyse the water availability condition in Bengawan Solo Watershed, the simulation of river flow and water balance condition were done in Bengawan Solo River. Simulation of river flow and water balance conditions were done with ArcSWAT model using climate data from CCAM, DEM SRTM 90 meter, soil type, and land use data. The results of this simulation indicate there is (i) The CCAM data itself after validation has a pretty good result when compared to the insitu data. Based on CCAM simulation results, it is predicted that in 2040-2069 rainfall in Bengawan Solo River Basin will decrease, to a maximum of only about 1 mm when compared to 1971-2000. (ii) The CCAM rainfall prediction itself shows that rainfall in Bengawan Solo River basin will decline until 2069 although the decline itself is not significant and tends to be negligible (rainfall is considered unchanged) (iii) Both in the DJF and JJA seasons, precipitation is predicted to decline as well despite the significant decline. (iv) The river flow simulation show that the water resources in Bengawan Solo River did not change significantly. This event occurred because the rainfall also did not change greatly and close to 0 mm/month.

1. Introduction
The water resources is one of the important issues that can affect many things. For example, in America, water resources of the Midwestern United States have a significant collective impact on multiple economic sectors in the US, North America, and the world [1]. Climate change can impact water resources through its impact into quantity, variability, timing, form, and intensity of precipitation [2].

Impacts of climate change are already evident in Indonesia and will likely worsen due to further human-induced climate change. Rising concentrations of GHG (greenhouse gas) will continue to raise the surface and ocean temperatures, change precipitation patterns, increase sea levels, and cause various other impacts from more frequent forest fires to increased health risks. Climate change will also continue to affect ‘natural’ climate variability, such as El Niño, and may lead to more frequent
and more intense weather events [3] and global sea-level rise is currently increasing at about 2mm per year and is projected to accelerate to a rate of about 5mm per year over the next century, a change of this magnitude will undoubtedly result in significant losses of Indonesia’s 80,000km of coastline, affecting thousands of islands and associated marine resources [4].

The Bengawan Solo River is the largest river on the island of Java [5], so spatial and temporal climate variability are key characteristics in hydrologic modelling. Distributed hydrological models like SWAT, it is designed to predict the impact of management on water, sediment and agricultural chemical yields in ungauged catchments [6]. This research aim to predict and simulate the impact of climate change into water resources in Bengawan Solo River Basin. Most areas in Bojonegoro are located in the Solo River watershed, which is a flood-prone area. Flooding is mostly caused by Bengawan Solo River basin overflow; the higher the intensity of the overflow, the more flooding there is downstream. The districts with the highest potential for flooding are Padangan, Kalitidu, Malo, Trucuk, Bojonegoro, Sumberejo, Kanor and Baureno.

2. Data and Methods

2.1. Data

Research data used in this research include two things:

1) In situ Data/ Station Measurement

   In situ data is measurement data that obtained from PUSAIR. The data that used is data from 2000-2013.

2) CCAM Modeling Data

   CCAM modeling data is obtained from CCAM model simulation results and have monthly temporal resolution. It is climate data. The data that used is historical data from 1971-2005 and RCP data for 2006-2069.

2.2. Methods: Modelling with CCAM (Conformal Cubic Atmospheric Model)

The Conformal Cubic Atmospheric Model is a global atmospheric model principally developed for atmospheric climate modelling and regional climate downscaling [7][8]. CCAM employs a conformal cubic grid to model the atmosphere without requiring lateral boundaries [9]. CCAM is a hydrostatic atmospheric model with two-time-level semi-implicit time differencing. It uses semi-Lagrangian advection associated with bicubic horizontal interpolation and total-variation-diminishing vertical advection. In a typical case, CCAM runs with 18 vertical levels and employs a C48 grid on which there are 48 x 48 grid points for each of the six cubic panels (i.e., N^2 = 6 x 48 x 48 grid points in the horizontal) [7].

In this case, RCP 4.5 data is used as the basis for the modelling and prediction of climatic conditions until 2069 by CCAM. Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilizes radiative forcing at 4.5 Watts per meter squared in 2100 [10].

3. Results and Discussion

Bengawan Solo River basin is the largest river basin in Java and have geographical position in 110^0 18’ and 112^0 45’ E and 6^0 49’ and 8^0 08’ S. The basin belongs administratively to two provinces, Central Java and East Java. The majority of the Upper Solo River basin belongs to Central Java Province while the majority of the Lower Solo River basins belongs to East Java Province. The basin covers 17 regencies: Boyolali, Klaten, Sukoharjo, Wonogiri, Karanganyar, Sragen, Blora, Rembang, Ponorogo, Madiun, Magetan, Ngawi, Bojonegoro, Tuban, Lamongan, Gresik, Pacitan; and 2 municipalities: Surakarta and Madiun [5]. Figure 1 shows the map of Bengawan Solo River Basin.
The majority of riparian areas in the Solo River District in Bojonegoro prone to flooding are flooded 5–6 times annually, covering a total area of 33.59 ha. The areas most susceptible to flooding cover 25.28ha, with an extensive flooding frequency of more than 7 times/year. Meandering rivers cause differences in flooding frequency in each sub-district. Residential areas in the district of Bojonegoro flood 5–7 times each year and 47 per cent of the district is affected. Based on data from the Bojonegoro Regional Disaster Management Agency, there were as many as 16 floods in 2010 [12].

The rainfall pattern in the Java Island area, including Bengawan Solo, generally has a monsoonal type [13]. Type monsoonal type means maximum rainfall occurs in December-January-February (DJF) and minimum rainfall occurs in June-July-August (JJA). Based on the analysis of station measurement data (insitu data) it can be seen that in Bengawan Solo Basin area of Ngawi, Bojonegoro, and Ngrambe, the maximum rainfall is around December-January-February. While the minimum rainfall occurs around June-July-August. This indicates that rainfall in Bengawan Solo Basin has monsoonal pattern. Rainfall in Bengawan Solo Basin area in 2000-2013 has maximum value around 400 mm / month in wet season (December-January-February) and around 50 mm / month in dry season (June-July-August) (Figure 2).

Meanwhile, according to CCAM data simulation, rainfall composite in Bengawan Solo Basin in 2006-2013 indicates that maximum rainfall also happened in December-January-February and minimum rainfall happened in June-July-August. However, there is considerable bias between the
maximum precipitation quantities simulated by CCAM when compared to observational data (in situ measurements / stations). The CCAM data itself shows that the maximum rainfall in Ngawi and Bojonegoro is about 300 mm/month (Figure 3).

CCAM data after being validated by observation data/station data shows good performance in simulating monthly rainfall conditions in Bengawan Solo River Basin. The correlation of CCAM rainfall data and station data in Ngawi reaches 0.82 while in Bojonegoro the value is 0.91. This indicates that CCAM is sufficiently able to simulate rainfall conditions in Bengawan Solo River Basin and its simulation results can be used in the analysis of water resources conditions in Bengawan Solo River basin.

![Composit Rainfall in Bengawan Solo Watershed 2006-2013 Based On CCAM Data](image)

**Figure 3.** Composit Rainfall in Bengawan Solo Watershed (2000-2013) Based On CCAM Data

The condition of water resources can be influenced by many things. In the present study the condition of water resources to be discussed is viewed from the rainfall condition. This is because rainfall is one of the main factors that can determine the condition of water resources in a region. The rainfall itself is part of weather parameters that can change and be influenced by climate change phenomena.

To determine climate change occurrence in Bengawan Solo River Basin, the temperature simulation plot was conducted in 1971-2000 and CCAM also predict temperature conditions in 2040-2069. From the the that temperature plot, it was observed that in 1971-2000 the temperature in the Bengawan Solo basin is relatively small around 300-302 K or 27-29 °C (Figure 4a). While in 2040-2069, the temperature is predicted to increase reach about 302-304 K or 29-31 °C (Figure 4b). Anomaly temperature plot was also conducted to determine temperature change during the period 2040-2069 when compared with the period 1971-2000. It is seen that the changes occurring during the history (1971-2000) as compared to RCP (2040-2069) are about 1.7-2.7 K (Figure 4c).

![Temperature Simulation Plot](image)

(a)  (b)
Climate change is believed to affect the rainfall conditions in Bengawan Solo River Basin. In the period 1971-2000, rainfall in Bengawan Solo was in the range of 50-250 mm with maximum conditions in the southwestern part of Central Java reaching 400 mm (Figure 5a). Conditions are not much different is predicted to occur in 2040-2069 (Figure 5b). Therefore, the CCAM model shows a decrease in rainfall in 2040-2069 when compared to 1971-2000 only about 0-1 mm.

Rainfall simulation in Bengawan Solo, especially in Ngawi and Bojonegoro until 2069 are predicted to decrease. It is shown in figure 6 that the linear regression shows the negative value on slope (x coefficient). Nevertheless, the coefficient value of x in linear regression process is very small.
even close to 0. This means that until 2069, there will be a decrease of rainfall in Bengawan Solo basin but the decrease itself will not be too significant.

**Figure 6.** Monthly Rainfall Prediction (2006-2067) in Bengawan Solo Based on CCAM Data

To know how the effect of climate change on rainfall condition in wet season in Bengawan Solo River Basin, there is plot of rainfall simulation until 2069 is for DJF season. It is seen that in Bojonegoro, rainfall is predicted to decrease as evidenced by the slope of the linear regression line decreasing with the coefficient of x is negative. However, the decrease will not be significant because the slope value is near 0 (Figure 7).

In contrast to Bojonegoro, the increase in precipitation is predicted to occur in Ngawi until 2069. This is due to the positive slope of linear regression line. However, the increase will not be too significant because the value of its slope is close to 0 (Figure 7).

**Figure 7.** Monthly Rainfall Data in DJF Season (2006-2069) Based on CCAM Data

To find out how the effect of climate change on rainfall conditions in the dry season in Bengawan Solo River Basin, there is plot of rainfall prediction up to 2069 specifically on JJA season. It can be seen that both in Bojonegoro and Ngawi, rainfall is predicted to decrease as evidenced by the slope of the linear regression line that decreases and the coefficient of x is negative. However, the decrease will not be significant because the slope value is close to 0 (Figure 7). The decreases of rainfall in Bojonegoro region itself is predicted to be higher when compared with Ngawi in the JJA season because the coefficient of x in Bojonegoro is much more negative when compared with Ngawi.

If water resources are observed from rainfall conditions, it can be predicted that future water resources conditions in Bengawan Solo River Basin until 2069 will not change much. It will be a
decline but the value is not significant enough. This is due to by linear regression analysis, the slope of the regression line is close to 0 mm/month which means the decrease is close to 0.

![Figure 8. Monthly Rainfall Data in JJA Season (2006-2069) Based on CCAM Data](image)

To better representation about the condition of water availability in Bengawan Solo River, calculation and simulation of the Bengawan Solo River discharge condition was done using ArcSWAT software. The results of this simulation found that the future of Bengawan Solo river discharge will not change much. According to the results of linear regression, it was found that in the Ngawi area, the Bengawan Solo River discharge will decrease by about 3x10^-5 m^3/sec per month and the flow of Bengawan Solo river in Bojonegoro will decrease about 6x10^-6 m^3/sec per month (Figure 9). The magnitude is very small and close to 0 so it can be concluded that the Bengawan Solo River discharge in the Ngawi and Bojonegoro areas is fixed. But different with [14], he has explored different approaches to precipitation input in an alpine area of large topographic relief and concluded that radar, combined with rain gauge data, performed better than gauge-only data. Consequently, these studies have highlighted the need for additional research to improve precipitation input to SWAT simulations.

![Figure 9. Monthly Average Discharge (2006-2069) in Bengawan Solo River Based On CCAM Data](image)

4. Conclusions
CCAM data has good validation results when compared to in situ data. This means that CCAM data can be used for analysis of rainfall conditions in Bengawan Solo basin. Climate change is predicted to occur in Bengawan Solo basin as evidenced by the predicted rise in temperature in Bengawan Solo
River Basin in 2040-2069 compared to temperatures in 1971-2000 based on CCAM data. This resulted in a decrease in rainfall in the period 2040-2069 even though the maximum decrease is only 1 mm when compared with the year 1971-2000. CCAM predicts there will be a decrease in rainfall up to 2069 in Bengawan Solo (Ngawi and Brojonegoro) watersheds although the decrease is not significant and close to 0. This means that the rainfall conditions in Bengawan Solo basin will not change much until 2069. This means the water resources in Bengawan Solo River Basin until 2069 is fixed.

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Acknowledgments
The authors would like to thank to PSTA-LAPAN (Centre of Atmospheric Science and Technology-National Institute Of Aeronautics and Space) for their support both morally and materially so that the writer can finish this research.