Development of an Integrated Agricultural Planning Model Considering Climate Change

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Abstract. The goal of this study is to develop an agriculture planning model in order to sustain the future water use under the estimation of crop water requirement, water availability and future climate projection. For this purpose, the Citarum river basin which is located in West Java – Indonesia is selected as the study area. Two emission scenarios A2 and B2 were selected. For the crop water requirement estimation, the output of HadCM3 AOGCM is statistically downscale using SDSM and used as the input for WEAP model developed by SEI (Stockholm Environmental Institute). The reliability of water uses is assessed by comparing the irrigation water demand and the water allocation for the irrigation area. The water supply resources are assessed using the water planning tool. This study shows that temperature and precipitation over the study area are projected to increase in the future. The water availability was projected to increase under both A2 and B2 emission scenarios in the future. The irrigation water requirement is expected to decrease in the future under A2 and B2 scenarios. By comparing the irrigation water demand and water allocation for irrigation, the reliability of agriculture water use is expected to change in the period of 2050s and 2080s while the reliability will not change in 2020s. The reliability under A2 scenario is expected to be higher than B2 scenario. The combination of WEAP and SDSM is significance to use in assessing and allocating the water resources in the region.

1. Introduction

Climate change, population growth and economic development are three factors likely to affect the availability of water resources for agriculture in the future. The demand and supply of water for irrigation will be influenced not only by the changes in climate and subsequent changes in hydrology but also by the increase in the competition for water in the future between the agricultural and the non-agricultural users, given the increasing population and associated economic development would impose pressure on water resources.

Adaptations relating water resources to agriculture are very important. A number of existing options can be used to adapt water resources for agriculture under climate change conditions in the future. In most studies, the sustainability of water uses is not incorporated in the evaluation of adaptation strategies of water resources for agriculture under possible climate change scenarios.
The assessment of future climate change impact at regional scales is vital for climate change adaptation issues. However, many researches were done on how to bridge the gap between the Global Circulation Model (GCM) output and the need of catchment scale assessment. Accordingly, downscaling methods have been developed to link GCM outputs at coarse resolutions with surface weather variables at finer resolutions. One of the statistical downscaling, Statistical Downscaling Model (SDSM), was developed by Wilby [1].

The hydrological response to climate change has been studied through the application of watershed-scale hydrological models driven by Global Circulation Model (GCM) scenarios of future climate (e.g. [2], [3], [4], and [11]). Water Evaluation and Planning (WEAP) as the distributed hydrology model integrates a range of physical hydrology processes with the management of the demands and installed infrastructure in a seamless and coherent manner [5]. It was used to assess the multiple scenario analysis, including alternative climate scenarios and changing of human intervention. Thus, WEAP was successfully applied to assess future climate impact on hydrology ([6], [11]).

In this study, the agriculture planning model is developed to determine how reliable water use in agriculture considering the future climate change. The model was developed using SDSM and WEAP. SDSM is used to downscale the future climate and WEAP allows the simulation and analysis of various scenarios of water allocation and user behaviour.

2. Method

In this study, the impact of climate change on water resources and agriculture was assessed using an integrated assessment approach (Figure 1). Three steps were applied to project the future climate in the study area, assessing the impact of future climate to the water availability and evaluate the irrigation management scenarios to the reliability of future water use in agriculture. The first step is the future climate projection. In this step, the Global Circulation Model namely Hadley Centre Coupled Model version 3 (HadCM3) was assigned. Two emission scenarios A2 and B2 were applied to project the future climate in the study area. The statistical downscaling SDSM was applied to generate the watershed scale spatial resolution of future climate in the study area. The second step is assessment of the future water availability. In this step, the WEAP hydrological model was applied to evaluate to water availability based on the downscaled climate output resulted from the first step. The model also assessed the future irrigation water requirement based on the irrigation management scenarios. Furthermore, the model evaluates the water allocation for the irrigation based on the irrigation water demand and supply. The last step is applying the reliability index to evaluate which irrigation management option is reliable for the irrigation water use under climate change in the future. The detail of each step is explained more detail as follows:
2. 1.  **Future Climate Projection**

The future climate was projected in the period of 2020s (2011 – 2040), 2050s (2041 – 2070) and 2080s (2071 – 2099). To describe the future climate, the temperature and precipitation were projected based on the output of Hadley Centre Coupled Model version 3 (HadCM3) GCM developed by Hadley Center, UK. The climate was projected under two emission scenarios A2 and B2 [2]. To increase the resolution of global to local scale, we used SDSM to downscale the climate variables. The SDSM establish the empirical relationship function (F) between the predictors and the predictand. The function is a deterministic/stochastic function which is conditioned by predictors and predictand as the follow equation:

\[
a = F (b)
\]  

where a is the predictand and b are the predictors

In this study, the GCM output employed as the predictors and the local climate variables as the predictand. To calibrate the SDSM, the atmospheric predictor variables from the National Center for Environmental Prediction (NCEP) reanalysis were used [1]. The temperature and precipitation of year 1961 – 2000 from four stations (Citarum, Cibeet, Cikarang and Bekasi) was used as the predictand.

2. 2.  **The hydrological model**

The WEAP package tool is used to model the hydrological process in the study area. WEAP is the computer modelling package design, which is used for simulation of water resources
system and trade-off analysis. It operates on the basic principle of water balance model that defines the process on a watershed scale. The supply is defined as the amount of precipitation that falls on the watershed, which is depleted through the watershed process, water uses, and the accretion to the downstream. Moreover, it enables integrated assessment of watersheds’ climate, hydrology, land use, infrastructure and water management priorities. WEAP has been used to model the impact of climate change, land use and adaptation scenarios on water resources (e.g. [7], [8], [9], [10]).

2.3 The Agricultural Water Use Reliability

Reliability (Cr), in the present study, is defined as the probability that the available water supply meets the water demand during the period of simulation. Let's define the criterion x, for each time period (t), if water demand (D) is more than water supply (S) than x equal to 1, otherwise x equal to 0. Than Cr is calculated as:

\[
Cr = \left(1 - \frac{\Sigma x}{n}\right) \times 100\%
\]  

(2)

where n is the number of analysis time periods.

In this study, the water use reliability was applied for evaluating the reliability of future water availability for irrigation water. The index of the agriculture water use reliability is applied to evaluate two irrigation management scenarios in the future period. The first irrigation scenario is by increasing the irrigation area, and the second scenario is by increasing the cropping intensity.

2.4 Case study- Citarum River Basin, Indonesia

The West Tarum Canal (WTC) irrigation system in the Citarum river basin Indonesia has been selected as the study area. The canal extends from east to west and passes agricultural, industrial and urban areas. The area is categorized as a tropical area with the average temperature of 24.7°C – 27.3°C, the average annual precipitation range of 1500 – 4000 mm and the humidity is about 80 – 95 %. The rainfall mostly falls in the wet season during November to April. The wet season is followed by the dry season during May to August.

The water in WTC canal is supplied by nearby sub-catchments: namely, Citarum, Cibeet, Cikarang and Bekasi (Figure 2). The WTC canal distributes water to the irrigation area, domestic and industry along the canal.
3. Result and discussion

3.1. Hydrology Model and Future Climate Projection

WEAP model indicates the reasonable ability in simulating long term monthly time series of stream flow. At Citarum sub catchment, monthly stream flows from year 1994–2009 were simulated with a bias of -0.24 %, Nash-Sutcliffe of 0.58 and R=0.78 (n=180 months). At Cibeet sub catchment, the monthly flows from year 1987 – 2005 were simulated with a bias of -0.34%, Nash-Sutcliffe of 0.64 and R=0.81 (n=216 months). At Cikarang sub catchment, the monthly flows of year 1987 – 2005 were simulated with a bias of 1.5%, Nash-Sutcliffe of 0.52 and R=0.73 (n=216 months). At Bekasi sub catchment, the monthly flow of year 1987-2005 was simulated with a bias of 0.08%, Nash-Sutcliffe of 0.66 and R=0.79 (n=216 months).

Future climate was projected based on the output of HadCM3 GCM and downscaled using SDSM application under A2 and B2 emissions scenarios. Result shows, the temperature and precipitation are projected to increase in the future periods compared with the baseline period. The A2 and B2 climate projections are warmer and wetter than the baseline period.

3.2. Future temperature

The temperature at the Cikarang and Bekasi sub basin under A2 scenario increased the most i.e. by 0.33, 0.99 and 1.63 °C, respectively, in the 2020s, 2050s and 2080s. On the other hands, the temperature in the Cibeet sub basin will decrease about 0.36 oC and investigated an increase about 0.24 in 2050s and 1.00 °C in 2080s under A2 scenario. As the average, the temperature will increase about 0.15, 0.74 and 1.47 oC in the 2020s, 2050s and 2080s respectively under A2 scenario. Under the B2 scenario, the temperature was investigated to
increase about 0.16, 0.50 and 0.97 oC in the 2020s, 2050s and 2080s periods, respectively.

3. 3. Future precipitation
The SDSM outputs show an increasing of precipitation in all sub basins for the future periods under A2 and B2 scenarios. The precipitation under DJF, JJA and SON periods under A2 and B2 scenarios increased in the future while the precipitation under MAM periods will decrease in the future for A2 and B2 scenarios. Comparing with the baseline periods, the precipitation under A2 scenario will increase more than the B2 scenario. In the A2 scenario, the precipitation will increase about 23, 55 and 88 % for the periods 2020s, 2050s and 2080s, respectively. In the B2 scenario, the precipitation is expected to increase about 27, 35 and 45% for the periods 2020s, 2050s and 2080s, respectively, compared with the baseline period.

3. 4. Water Availability and Irrigation Water Requirement under Climate Change
It is seen that the A2 and B2 scenarios produce a wide range of changes in the hydrology of the sub basin. It shows that for the three future periods, the stream flows are increasing in both scenarios when compared with the baseline period (Table I). The periods under A2 scenario shows an increase of the main stream flow of about 6.6, 53.1 and 111.7% for the periods of the 2020s, 2050s and 2080s, respectively.. Under B2 scenario, the mean flow of future periods is expected to respectively increase about 12.4, 37.3 and 67.1% in the 2020s, 2050s and 2080s periods.

The stream flow in the month of the whole year is projected to increase under A2 and B2 scenarios for the periods of the 2020s, 2050s and 2080s. However, the flows of the months of October, November and December are expected to decrease under A2 and B2 scenarios for the 2020s periods.

Table 1. Water availability under a2 and b2 scenario

| Period | Emission Scenario | Water availability (x10^6 m^3) |
|--------|------------------|------------------------------|
|        |                  | Citarum | Cibeet | Cikarang | Bekasi | Total    |
| Baseline |                  | 1253    | 1660   | 1757     | 2344   | 7013     |
| 2020s   | A2               | 1625    | 1656   | 1971     | 2225   | 7477     |
|         | B2               | 1759    | 1735   | 2058     | 2331   | 7884     |
| 2050s   | A2               | 2421    | 2409   | 2807     | 3106   | 10742    |
|         | B2               | 2183    | 2178   | 2485     | 2784   | 9630     |
| 2080s   | A2               | 3523    | 3505   | 3786     | 4038   | 14852    |
|         | B2               | 2628    | 2741   | 3054     | 3292   | 11715    |

Source: [11]

Table 2 shows the comparison of annual irrigation water requirement between the historical period and future projection under two emission scenarios. It clearly shows that by considering the change in climate, the irrigation water requirements (IWR) will decrease in the future in both emission scenarios. Under A2 scenario, the total IWR will decrease about 16%, 37% and 63% compared with the historical in the period of 2020s, 2050s and 2080s, respectively. Similarly, under B2 scenario, the IWR will decrease about 20%, 24% and 44% on the period of 2020s, 2050s and 2080s, respectively. Thus, under A2 scenario the IWR is expected to decrease more than under B2 scenario.
Table 2. Irrigation water requirement under A2 and B2 scenario

| Period | Emission scenario | Average Annual Irrigation Water Requirement (x 10^6 m^3) |
|--------|-------------------|-----------------------------------------------------|
|        |                   | Citarum | Cibeet | Cikarang | Bekasi | Total  |
| Baseline |                   | 58.2    | 390.4  | 344.8    | 119.9  | 913.3             |
| 2020s   | A2                | 55.8    | 336.1  | 279.5    | 95.2   | 766.7             |
|         | B2                | 52.3    | 323.3  | 262.1    | 90.0   | 728.5             |
| 2050s   | A2                | 47.5    | 257.2  | 202.2    | 69.8   | 574.7             |
|         | B2                | 51.2    | 304.5  | 251.1    | 84.2   | 691.0             |
| 2080s   | A2                | 29.9    | 138.6  | 120.3    | 40.8   | 329.6             |
|         | B2                | 43.2    | 207.8  | 207.9    | 57.6   | 515.6             |

Source: [11]

3.5. Irrigation Water Use Reliability under Future Climate Change

The water use reliability was assessed based on the impact of future climate only. The future water allocation for the irrigation and the change of future water requirement for the irrigation was compared and the reliability index was calculated. In future period, the water use reliability is expected to decrease compared with the historical period. As shown in the Figure 2, the reliability will not change in the period of 2020s under both A2 and B2 climate projection because the water allocation for the irrigation is able to fulfil the irrigation water requirement. It means that there will be no water shortages for the irrigation in the period of 2020s in the future. However, the decreasing of the water allocation for the irrigation in the period of 2050s and 2080s impact to the decreasing of the reliability index for the water use for irrigation in the future period. As shown in the Figure 3, under A2 emission scenario, the water use reliability is expected to decrease about 15% and 26% in the period of 2050s and 2080s, respectively. Similarly, under B2 scenario, the water use reliability is expected to decrease about 20% and 43% in the period of 2050s and 2080s, respectively, because of the decreasing water allocate to the irrigation.

![Figure 3 Agriculture water use reliability under historical and future climate projection](image-url)
3. 6. **Impact of irrigation management scenario on the reliability of irrigation water use**

This study focuses on the development of the integrated agriculture planning model considering the future climate change. The framework is developed to incorporate the climate change on the water management especially in agriculture. The result of the implementation of the integrated agriculture planning model to evaluate the future management scenario is shown in the Figure 4.

Considering the climate change itself and in combination with the various irrigation management scenarios, it is found that the reliability is expected to decrease in the future. Even without any changes in the irrigation area and crop, the shortage in irrigation water supply is likely to increase in the future due to less water that will be allocated for irrigation as a consequence of the simultaneously increasing demands from domestic and industrial users. Therefore, in combining climate change with different scenarios, the irrigation water use reliability is expected to decrease in the future.

However, the decreasing of the reliability index is expected to be higher when the irrigation area is increasing rather than the increasing of the crop intensity. The increase of irrigation area will increase the annual IWR without change the monthly IWR. On the other hand, the increase of cropping pattern will increase not only the annual IWR but also the monthly pattern of the IWR. Therefore, the water shortage where the irrigation water supply is not able to fulfil the irrigation water requirement, is expected to increase in the future if the increasing of cropping pattern is applied.

![Figure 4](image-url)  
Figure 4 Irrigation water use reliability under different irrigation management scenario in the future

The result of this section shows that the increasing of the irrigation area is more reliable in term of water use for agriculture in the future. The result also shows that the framework is able to apply for the assessment of the future management scenario considering climate change.

4. **Conclusion**

This study uses the SDSM and WEAP model in order to assess the impact of climate change on the hydrology in the Citarum river basin. The basin was modelled quite well by the WEAP application. The model was able to simulate the stream flow during the analysis periods.
The SDSM was used to downscale the coarse scale of GCM output to the finer resolution of basin scale as it is required by the hydrological model. The SDSM performed well to downscale the temperature and precipitation in the study area. The temperature projection indicates the increasing of temperature for the future compared with the baseline period. The daily precipitation is projected to increase in the future compared with the baseline periods.

The water availability was simulated using the combination of SDSM and WEAP hydrological model. The water availability was projected to increase in the future under two emission scenario A2 and B2. The study intended to cater the research in the developing country using the low-cost assessment tool to increase the awareness of water resources change due to future climate change. By comparing the irrigation water demand and water allocate to agriculture, the reliability of agriculture water use is expected to change in the period of 2050s and 2080s while the reliability will not change in the period of 2020s. The reliability under A2 scenario is expected to be higher than B2 scenario.

This study provide a useful tool to assess the impact of climate change on future water availability as the input for future water planning and assess the reliability of agriculture water use in the future. The result provides the input for the decision maker to take decision on how to manage water resources under future climate change.

5. References

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