Water Availability Under Future Climate Change: A Study of Citarum River Basin, Indonesia

I Putu Santikayasa [1,2], Mukand S. Babel [1], and Sangam Shrestha [1]

[1] Water Engineering and Management, Asian Institute of Technology, Pathumthani 12120, Thailand.
[2] Department of Geophysics and Meteorology, FMIPA, Bogor Agricultural University, Indonesia.
Email: psantika@gmail.com

Abstract— **This study assessed the impact of climate change on future water availability in the Citarum river basin, Indonesia. Future climate was projected based on the output of HadCM3 GCM under A2 and B2 scenarios and downscaled using SDSM package application. The hydrological processes were modelled using WEAP application. The result suggested an increase of temperature as well as precipitation in the period of the 2020s, 2050s and 2080s. The water availability is projected to increase in the future.**

Keywords—climate change; statistical downscaling; WEAP; SDSM water availability

I. Introduction

The assessment of the impact of future climate change at regional scales is vital for climate change adaptation issues. In tropical area, the temperature and precipitation is expected to increase during 21 century [1]. In regions which are expected to maintain or exceed historical water yields due to projected increases in precipitation, the hydrological regime is expected to change in terms of timing and magnitudes of seasonal stream flow.

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]). 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].

Although hydrological models are used within the GCMs, they are less reliable for analysis of surface and groundwater balances in local river basins [7]. Previous studies used GCMs coupled with water balance to investigate the potential effects of climate change on runoff and water resources in different areas under different conditions (e.g. [8], [9]). As a potential and popular method, hydrological models in combination with downscaled GCMs are usually used to project impacts of streamflow under climate change scenarios at river basin scale [8].

Here, the hydrological impact of climate change in the Citarum river basin will be further investigated using statistical downscaling (SDSM) and WEAP application.

II. Methodology

A. Study Area

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^{o} – 27.3^{o} 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 WTC canal is supplied water by nearby sub-catchments: namely, Citarum, Cibeet, Cikarang and Bekasi (Fig. 1). The WTC canal distributes water to the irrigation area, domestic and industry along the canal.

B. 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, and 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. [10], [9]).

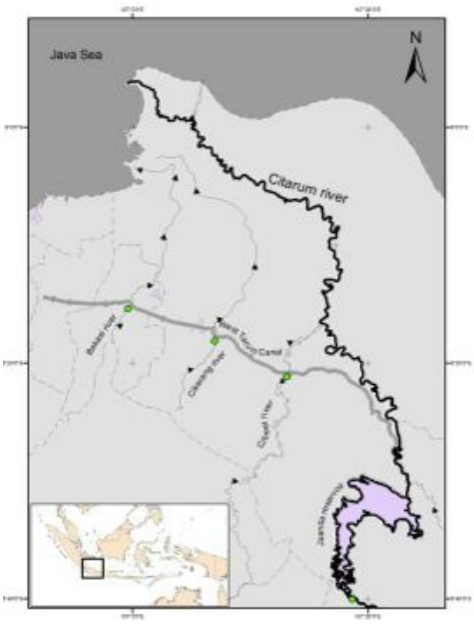

Fig. 1. Map of study area

C. 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. 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:

$$a=F(b) \qquad (1)$$

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 (Kalnay et al., 1996). The temperature and precipitation of year 1961 – 2000 from four stations (Citarum, Cibeet, Cikarang and Bekasi) was used as the predictand.

III. RESULT AND DISCUSSION

A. Hydrological model performance

Results indicate the reasonable ability of the WEAP model in simulating long term monthly time series of streamflow. At Citarum sub catchment, monthly stream flows from year 1994–2009 were simulated with a bias of -0.24 %, Nash-Sutclife 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-Sutclife 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-Sutclife 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-Sutclife of 0.66 and R=0.79 (n=216 months).

B. Future Climate Projection

In this study, the climate was projected based on the output of HadCM3 GCM and downscaled using SDSM application under A2 and B2 emissions scenarios. 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.

1) *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 ^{o}C, respectively, in the 2020s, 2050s and 2080s. On the other hands, the temperature in the Cibeet sub basin will decrease about 0.36 ^{o}C and investigated an increase about 0.24 in 2050s and 1.00 ^{o}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 (Fig. 2).

2) *Future precipitation:* The SDSM outputs show an increasing of precipitation in all sub basins for the future periods under A2 and B2 scenarios. Fig. 3 shows the projections of average monthly precipitation in the study area by SDSM for the baseline period and 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 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.

C. Water Availability 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 that the stream flow are increasing in the future for both scenarios (Table I). The periods under A2 scenario shows an increase, of about 6.6, 53.1 and 111.7% for the periods of the 2020s, 2050s and 2080s for the main stream flow compared with the baseline. Under B2 scenario, the mean flow of future periods is expected to increase about 12.4, 37.3 and 67.1% in the 2020s, 2050s and 2080s, respectively, compared with the baseline period.

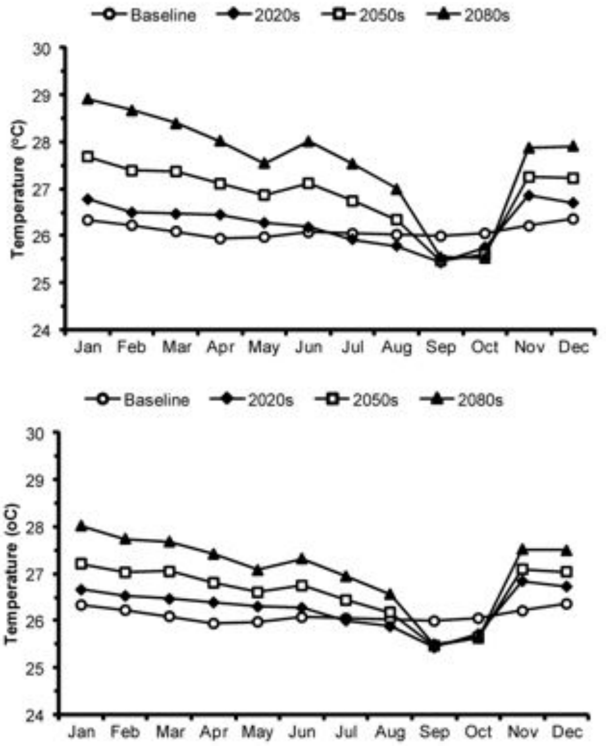

Fig. 2. Temperature projection under A2 (upper) and B2 (lower) emissions scenarios

The flows in the month of the whole year are 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 periods of the 2020s.

TABLE I. WATER AVAILABILITY UNDER A2 AND B2 SCENARIO

Period		Average annual water supply (mm)				
		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

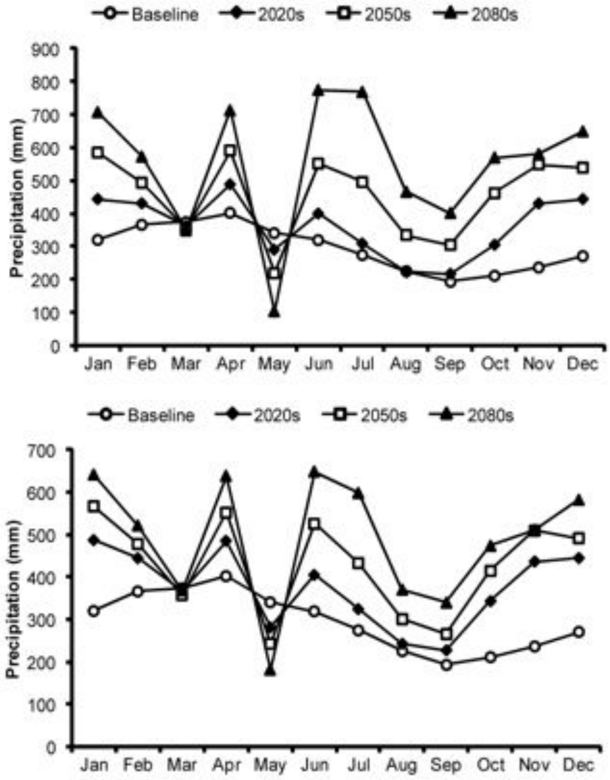

Fig. 3. Future precipitation projection under A2 (upper) and B2 (lower) emissions scenarios

IV. CONCLUSION

This study aimed to use the SDSM and WEAP model to assess the impact of climate change on the hydrology in the basin. The basin was modeled quite well by the WEAP application. The model was able to simulate the streamflow 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.

ACKNOWLEDGMENT

The authors wish to acknowledge the Meteorological, Climatological and Geophysical Agency (BMKG) and Coordinating Agency for Surveys and Mapping (Bakosurtanal), Indonesia for providing the climate and spatial data for the analysis.

REFERENCES

[1] IPCC, 2007: R.K. Pachauri, A. Reisinger (Eds.), Climate Change: Summary for Policymaker of Synthesis Report. Core Writing Team, Cambridge University Press, Cambridge

[2] Toth, B., Pietroniro, A., Conly, M.F., Kouwen, N., 2006. Modelling climate change impacts in the Peace and Athabasca catchment and delta: I-hydrological model application. Hydrol. Processes 20, 4197–4214.

[3] Nurmohamed, R., Naipal, S., De Smedt, F., 2007. Modeling hydrological response of the Upper Suiname river basin to climate change. J. Spatial Hydrol. 7 (1), 1–22..

[4] Forbes, K.A., Kienzle, S.W., Coburn, C.A., Byrne, J.M., Rasmussen, J., 2011. Modelling the impacts of selected GCM derived climate scenarios on the future hydrology of a hybrid watershed in the Oldman River watershed, Alberta, Canada. Clim. Change

[5] Wilby RL, Wigley TML. Downscaling general circulation model output a review of methods and limitations. Prog Phys Geogr 1997;21:530–48.

[6] Yates, D., J. Sieber, D. Purkey, and A. Huber-Lee, 2005: WEAP21—A Demand-, Priority-, and Preference-Driven Water Planning Model -- Part 1: Model Characteristics. *Water International*, **30,** 487-500.

[7] Samuels, R., Rimmer, A., Hartmann, A., Alpert, S., 2010. Climate change impacts on Jordan River flow: downscaling application from a regional climate model. Journal of Hydrometeorology 11, 860 e 879.

[8] Lu, E., Takle, E., Manoj, J., 2010. The relationship between climatic and hydrological changes in the upper Mississippi River basin: a SWAT and multi-GCM study. Journal of Hydrometeorology 11, 437 e 451.

[9] Xu, Z.X., Zhao, F.F., Li, J.Y., 2009. Response of streamflow to climate change in the headwater catchment of the Yellow River basin. Quaternary International 208, 62 e 75.

[10] Joyce, B., V. Mehta, D. Purkey, L. Dale, and M. Hanemann, 2011: Modifying agricultural water management to adapt to climate change in California's central valley. Climatic Change, 109, 299-316

[11] Purkey, D., A. Huber-Lee, D. Yates, M. Hanemann, and S. Herrod-Julius, 2007: Integrating a climate change assessment tool into stakeholder-driven water management decision-making processes in California. Integrated Assessment of Water Resources and Global Change, E. Craswell, M. Bonnell, D. Bossio, S. Demuth, and N. Giesen, Eds., Springer Netherlands, 315-329.