Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan Vol. 9 No. 1 (Maret 2019): 181-189

# IMPACT OF CHANGES IN CLIMATE AND LAND USE ON THE FUTURE STREAMFLOW FLUCTUATION: CASE STUDY MERANGIN TEMBESI WATERSHED, JAMBI PROVINCE, INDONESIA

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***Abstract.*** *Beside land use change, future climate change potentially alters streamflow fluctuation of a river basin in Indonesia. We investigated relative impact of changes in climate and land use on the streamflow fluctuation of a watershed in Jambi Province, Indonesia for future condition (2025). To account for the climate change, we simulated future rainfall and temperature scenarios using the downscaled rainfall and mean surface temperature of 24 CMIP5 GCM outputs with moderate scenario of RCP4.5. We used distributed hydrologic model (SWAT) to simulate relative impact of changes in climate and land use on the future streamflow fluctuation. The SWAT model performed well with the Nash-Sutcliff efficiency values of 0.80-0.85 (calibration) and 0.84-0.86 (validation). The results indicated that the climate change caused 32% decrease of the minimum discharge during dry season and 96% increase of the maximum peak discharge during rainy season. Meanwhile, the land use change led to 40% decrease of the minimum discharge in the dry season and 65% increase of the maximum peak discharge in wet season. Both changes indicated significant impact on the extreme events such as discharge and minimum discharge. The impact of the climate change on the increased peak discharge is more significant compared to that of the land use change. Meanwhile, the impact of the land use change on the minimum discharge is more significant compared to that of the climate change. The results of this study pointed out that both climate and land use changes potentially become crucial factors for the future discharge fluctuation in Indonesia.*

Keywords: *Cimate change, land use change, streamflow fluctuation, SWAT model*

(Diterima: 08-06-2018; Disetujui: 10-10-2018)

## 1. Introduction

Categorized as a humid tropical country, Indonesia has abundant water resources. According to Pereira et al. (2002), water is becoming scarce not only in drought prone regions but also in areas where rainfall is abundant. Annual quantity of available water exceeds demands in most regions in Indonesia. Nevertheless, water scarcity phenomenon in Indonesia occurs in almost all regions during dry season. Seasonal variability of streamflow is very high in most part of Indonesia causing unsecure water availability for agricultural activities. Predicted climate and land use changes are considered as the main drivers for future increased of rainfall and streamflow fluctuation (Boer and Faqih, 2004; Nayor et al., 2007; Junaidi and Tarigan, 2011; Tarigan et al., 2016; Tarigan, 2016a; Tarigan, 2016b). Therefore, water availability crisis driven by streamflow fluctuation can be a major constraint for agriculture development in coming decades and particularly in Asia and this will require major mitigation and adaptation strategies (Rijsberman, 2006). Aim of this study was to investigate relative impact of change in climates and land use change on the streamflow fluctuation of a watershed.

Impact of changes in climate and land use in streamflow fluctuation requires different mitigation and adaptation options. The ability to separate relative contribution of both factors enables us to set up priority on the appropriate mitigation or adaptation options (Tarigan et al., 2015; Tarigan et al., 2016a; Tarigan, 2016b; Tarigan, 2018). Impact due to the climate change is difficult to mitigate and therefore adaptation strategies are more appropriate. On the other hand, impact due to the land use changes especially those related to the plantation expansion can be mitigated by implementing good agricultural practices (Satriawan et al., 2017).

In Indonesia, the oil palm area increased from 0.7 million ha in 1990 to 11 million ha in 2015 (Ditjenbun, 2015; Tarigan et al., 2016). Additional land demand for palm oil production is expected to increase continuously in Indonesia in 2020-2050 (Wicke et al., 2011; Afriyanti et al., 2016). While plantation has improved farmer and regional economic, it has been subject to the environmental concerns (Klasen et al., 2016). The land use change alters local water cycle including increased transpiration (Roell et al., 2015; Hardanto et al., 2017), increased evapotranspiration (Babel et al., 2011; Meijide et al., 2017), decreased infiltration (Banabas et al., 2008; Tarigan et al., 2016), reduced minimum discharge (Adnan and Atkinson, 2011; Comte et al., 2012; Merten et al., 2016) and water quality (Sinukaban et al., 2000; Babel et al., 2011). All these changes potentially increase streamflow fluctuation in a river basin.

Besides the land use change, climate change is also considered as a potential factor for water cycle and streamflow fluctuation. The climate change alters temperature and the precipitation pattern. The higher the

doi: 10.29244/jpsl.9.1.181-189

temperature, the higher the evapotranspiration and the lower the annual streamflow volume are. According to Babel et al. (2014), Tmax is predicted to increase by 2.1 °C under A2 scenario and by 1.5 °C under B2 scenario in Bagmati River Basin, Nepal in 2080. Higher evapotranspiration intensified water deficits in dry season (Mcintyre, 2007). According to the Naylor et al., (2007), seasonal pattern of rainfall in Indonesia has changed with up to 75% decrease in rainfall in the dry season (July-September). Meanwhile, Hulme and Sheard (1999), predcited that during the wet season (December-February), parts of Sumatra and Kalimantan become 10 to 30 percent wetter by the 2080's. In contrast, rainfall pattern during the dry season (June-August) are becoming drier. Several methods can be used to investigate relative impacts of land use and climate change on streamflow fluctuation. The approaches can be classified as empirically-based and process-based. Empirical-based approaches use long-term historical data to analyze the changes (Li et al., 2004; Ma et al., 2008; Zhang et al., 2008; Bao et al., 2012; Mwangi et al., 2016). Process-based method implements physically-based hydrological models. The change impact is determined by varying climate and crop inputs and landuse settings (Khoi et al., 2014; Guo et al., 2016; Zhang et al., 2016). Process-based approach require more data as input and subject to high uncertainty in parameter estimation (Zhang et al., 2016; Xu et al., 2014). In this study we used semi process-based and distributed hydrologic model (SWAT) to analyze relative impact of changes in climate and land use on the streamflow fluctuations.

## 2. Materials and Methods

### 2.1. Study Site

The study site is located in Merangin Tembesi watershed, Jambi Province of Sumatra, Indonesia (Fig. 1). The Merangin Tembesi watershed area is approximately 1,345,500 ha and is experiencing rapid land use change, (Drescher et al., 2016).

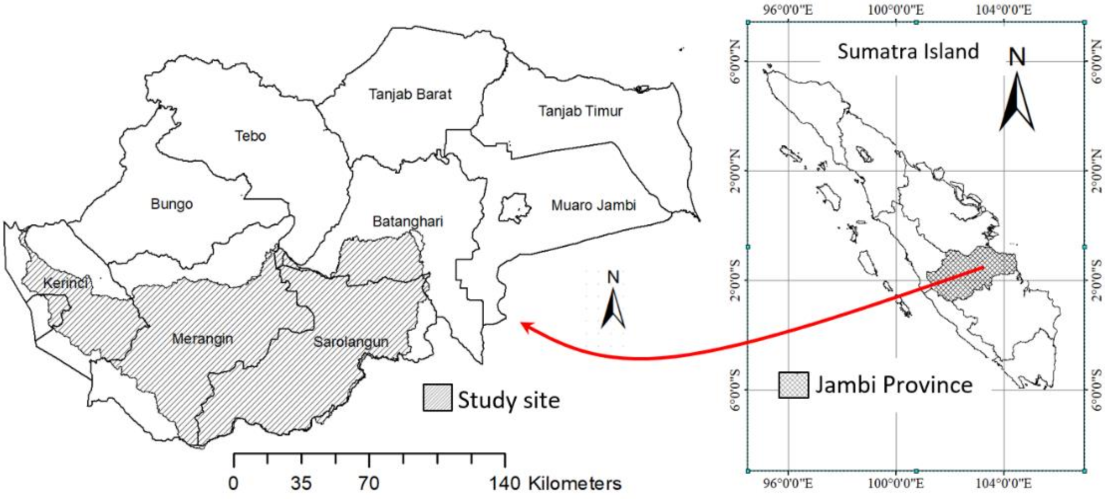

*Figure 1. Study site in Jambi Province of Sumatra, Indonesia*

### 2.2. Data Collection

We used semi process-based hydrological model (SWAT) to quantify the water balance of a watershed on a daily basis, climate change simulation and other water resource infrastructure (Arnold et al., 2012; Zuma et al., 2017). Input data for the SWAT model include soils, land use, temperature, humidity, radiation, and streamflow data (Table 1). Besides soil type boundary derived from soil map, we also carried out field data collection including hydraulic conductivity (SOL_K), bulk density (SOL_BD), available water content (SOL_AWC) and texture for the SWAT model input.

### 2.3. Land Use Change

Predicted land use changes in Merangin Tembesi watershed for year 2025 was based on the future concession permit of plantation crops obtained from various sources including Agricultural Plantation offices (Ditjenbun, 2015) and unpublished map from WARSI. The land use change alters water cycle characteristic such as infiltration, interception, and surface run off (Tarigan et al., 2016). These changes were reflected in the SWAT model input by adjusting relevant parameters such as CN (curve number), OV_N (Manning's "n" value for overland flow), SOL_K (saturated hydraulic conductivity (mm $h^{-1}$) and SOL_AWC (available water capacity of the soil (mm $H_2O$ $mm^{-1}$ soil) using field data and references as suggested in SWAT manual book.

Table 1. Sources of the model layer data, rainfall, climate and

discharge data

| Data type | Source Data | Resolution |
|---|---|---|
| Slope characteristics | DEM from SRTM (srtm.csi.cgiar.org) | 90 m |
| Soil types | Soil map from the Soil Research Institute, Bogor | 1:250,000 |
| Land use change | Land use map from the Regional Planning office (BAPPEDA) and | 1:100,000 |
| Rainfall data from Rantau Pandan, Siulak Deras, Muara Imat stations and climate data from Jambi, Pematang Kabau and Bungku stations. | BMKG office (Meteorology, Climatology and Geophysics Agency) and CRC990 (Collaborative Research Centre 990) | Daily data |
| Streamflow discharge from Muara Tembesi hydrological station | Ministry of Public Works (BBWS) | Daily data |

Table 2. Land use change from 2010 (baseline) to 2025

| **Land use types** | **2010 (baseline)** | | **2025 (predicted)** | | **Change** |
|---|---|---|---|---|---|
| | **ha** | **(%)** | **ha** | **(%)** | **(%)** |
| Plantation | 385,606 | 28.7 | 568,712 | 42,1 | 13.0 |
| Agroforest | 185,906 | 13.8 | 120,662 | 8,9 | -4.8 |
| Shrubland | 146,846 | 10.9 | 126,359 | 9.37 | -1.5 |
| Forest | 551,295 | 41.0 | 415,456 | 30.9 | -10.1 |
| Dry land farming | 55,610 | 4.1 | 79,476 | 6.00 | 1.8 |
| Settlement | 1,450 | 0.1 | 8,745 | 0.7 | 0.5 |
| Sawah | 10,234 | 0.8 | 17,247 | 1.3 | 0.5 |
| Bareland | 1,005 | 0.1 | 1,161 | 0.09 | 0.0 |
| Mangrove | 150 | 0.0 | 153 | 0.01 | 0.0 |
| Water and swamps | 7,460 | 0.6 | 7,598 | 0.56 | 0.0 |
| Total | 1,345,562 | 100 | 1,345,562 | | |

## *2.4. Climate Change Scenarios*

To account for climate change impact, we calculated the changes in the climatology of future rainfall and mean surface temperature scenarios over the studied region. The future changes were calculated respective to 1981-2010 baseline periods. We used simple delta method to downscale and correct biases of the rainfall and surface temperature data obtained from the outputs of 24 CMIP5 GCMs. To simplify the downscaling process, we used a bias correction tool developed by Faqih (2017), that is specifically designed to statistically downscale the outputs of CMIP5 GCMs for developing climate scenarios in Indonesia.

The model output from CMIP5 GCMs used the recent climate change scenario called as Representative Concentration Pathways (RCP) (Moss, 2010). There are four scenarios available in the long-term climate change projections of RCP scenarios based on their possible range of radiative forcing values in 2100, i.e. RCP2.6, RCP4.5, RCP6.0 and RCP8.5. For this study, we only used the moderate scenario of RCP4.5. The pathway of this scenario is “stabilization without overshoot”, which means that it stabilizes radiative forcing at 4.5 $Wm^{-2}$ (equal to 650 ppm CO2-equiv) in year 2100 without exceeding that value afterwards (Thompson et al., 2011).

## *2.5. SWAT Calibration and Validation*

We calibrated the model using version 2012 of the SWAT-CUP software package. The SWAT-CUP is an interface for auto-calibration that was developed for SWAT (Abbaspour, 2015). The calibration was carried out in year 2007-2009 and the validation in year 2013-2014. Nash-Sutcliff efficiency (NSE) and Percent Bias (PBIAS) were used to evaluate the result of the calibration and the validation. The NSE is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). The PBIAS measures the average tendency of the simulated data to be larger or smaller than the observations (Gupta et al., 1999). The optimum value is zero, and low magnitude values indicate better simulations. The model input parameters that were used for the calibration process and their fitted values after calibration are shown in Table 3.

Table 3. The initial and the calibrated values of SWAT input parameters

| Parameters | Descriptions | Initial value | Best fit values |
|---|---|---|---|
| ALPHA_BF | Baseflow recession constant | 0.0 – 1.0 | 0.91 |
| SOL_AWC | Available water capacity of the soil (mm $H_2O$/mm soil) | - 0.2 – 0.4 | 0.04 (V)[a] |
| OV_N | Manning’s “n” value for overland flow | - 0.2 – 1.0 | 0.29 (V)[a] |
| GW_DELAY | Groundwater delay time (days) | 30 – 450 | 57.2 |
| CN2 | Curve Number | -0.2 – 0.9 | 0.006 (V)[a] |
| GWQMN | Water depth in a shallow aquifer for a return flow (mm H2O) | 0.0 – 2.0 | 0.45 |
| GW_REVAP | Evaporation from the ground water (mm) | 0.0 – 0.2 | 0.07 |
| CH_N2 | Manning’s “n” value for the main channel | 0.0 – 0.3 | 0.15 |
| CH_K2 | Eff. hydraulic conductivity in the main channel alluvium (mm/hr) | 5.0 – 130 | 24.4 |
| SOL_K | Saturated hydraulic conductivity (mm $h^{-1}$) | - 0.8 – 0.8 | 0.12 (V)[a] |

[a] (V) = Variable fraction depending on land-use and soil, changes in calibration were therefore expressed as fraction

## 3. Result and Discussion

### *3.1. SWAT Model Performance*

The SWAT model performed well (Fig. 2) with the NSE values of 0.80-0.85 (calibration) and 0.84-0.86 (validation) and the PBIAS values ranges between -3 and 1.3 (calibration) and between 7.0 and 11.9 (validation).

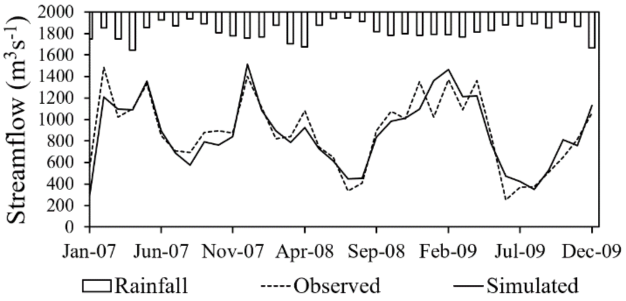

*Figure 2. Observed and simulated discharge of MT watershed*

After calibration and validation, the model was used to simulate relative impact of the land use change and climate change on the stream flow fluctuation. We simulated 3 scenarios for future condition (2025): a) impact of land use change, b) impact of climate change and, c) coupled impact of climate change and land use change.

### *3.2. Impact of Land Use Change on The Stream Flow Fluctuation*

In this scenario, the climate input parameter (rainfall and temperature) of the SWAT model was based on the baseline year (2010). Meanwhile, the soil and crop input parameter of the model was based on the year 2025 land use map (Table 2). The land use change led to 40% decrease of the minimum discharge in the dry season and 65% increase of the maximum peak discharge in wet season compared to those of baseline (Fig. 3; Table 4). The increased streamflow fluctuation was mainly caused by factors related to the soil degradation such as lower soil infiltration, higher bulk density, and increased CN (Curve Number) values. The low infiltration rate increases surface runoff component and in turn it increases the peak discharge during wet season and reduced the minimum discharge during consecutive dry season.

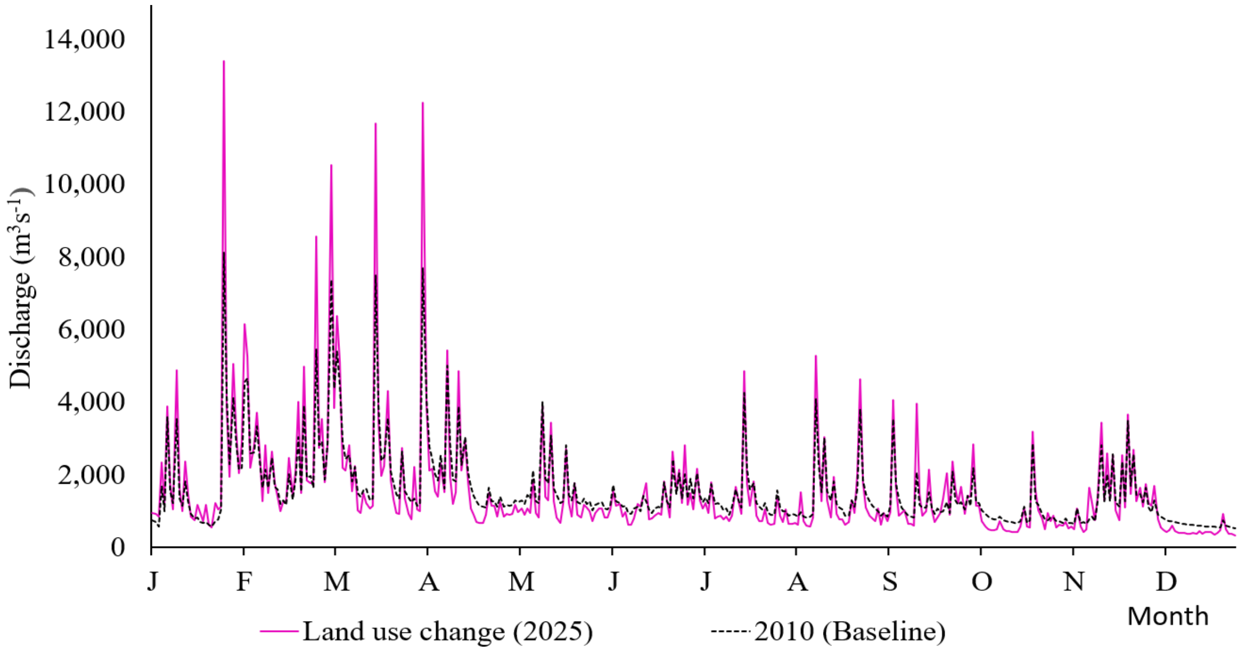

*Figure 3. Impact of the land use change on the discharge fluctuation*

### *3.3. Impact of The Climate Change on The Stream Flow Fluctuation*

In this scenario, we adjusted the climate input parameter (rainfall and temperature) to reflect climate change in 2025 but kept the soil and crop parameters unchanged based on the baseline land-use map.

The future rainfall calculated from the downscaled rainfall of 24 CMIP5 GCM outputs showed both negative as well as positive variability respectively to the baseline value in 1981-2010 periods (Fig. 4). To adapt Fig. 4 for the rainfall input of the SWAT model, we also considered other related studies. According to the Naylor et al. (2007), seasonal pattern of rainfall in Indonesia has changed with up to 75% decrease in rainfall in the dry season (July-September).

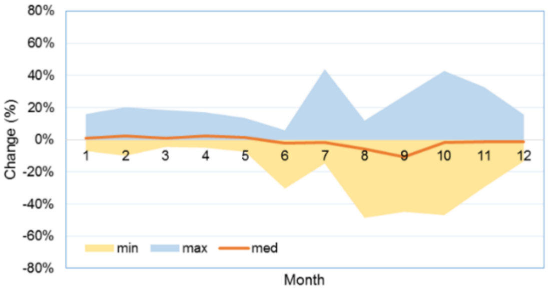

*Figure 4. Uncertainties in the change of future rainfall in the Merangin Tembesi Watershed (2025)*

Meanwhile, Hulme and Sheard (1999), predicted that during the wet season (December-February), parts of Sumatra and Kalimantan become 10 to 30 percent wetter by the 2080's. Into a certain extend, both these studies are in line with our climate change prediction. Considering our rainfall prediction using 24 CMIP5 GCM outputs and both studies, we adapt the rainfall input of the SWAT model by increasing baseline daily data by 20% during December-February (Hulme and Sheard, 1999) and reducing them by 10% during July-September according to the median value shown by red line in Fig. 4.

For the temperature input, we used the median value (red line) of the downscaled outputs of 24 CMIP5 GCMs (Fig. 5). Median value of the temperature scenarios in 2025s is around 0.6 °C with the highest value projected by the model reaches 1.1 °C.

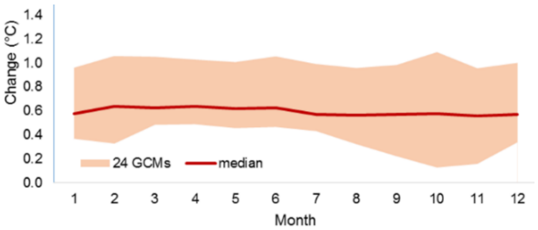

*Figure 5. Uncertainties in the change of future surface temperature under RCP4.5 scenario in the Merangin Tembesi Watershed (2025s)*

The predicted climate change showed 96% increase of the maximum peak discharge during rainy season and 32% decrease of the minimum discahrge during dry season compared to those of baseline (Fig. 6; Table 4).

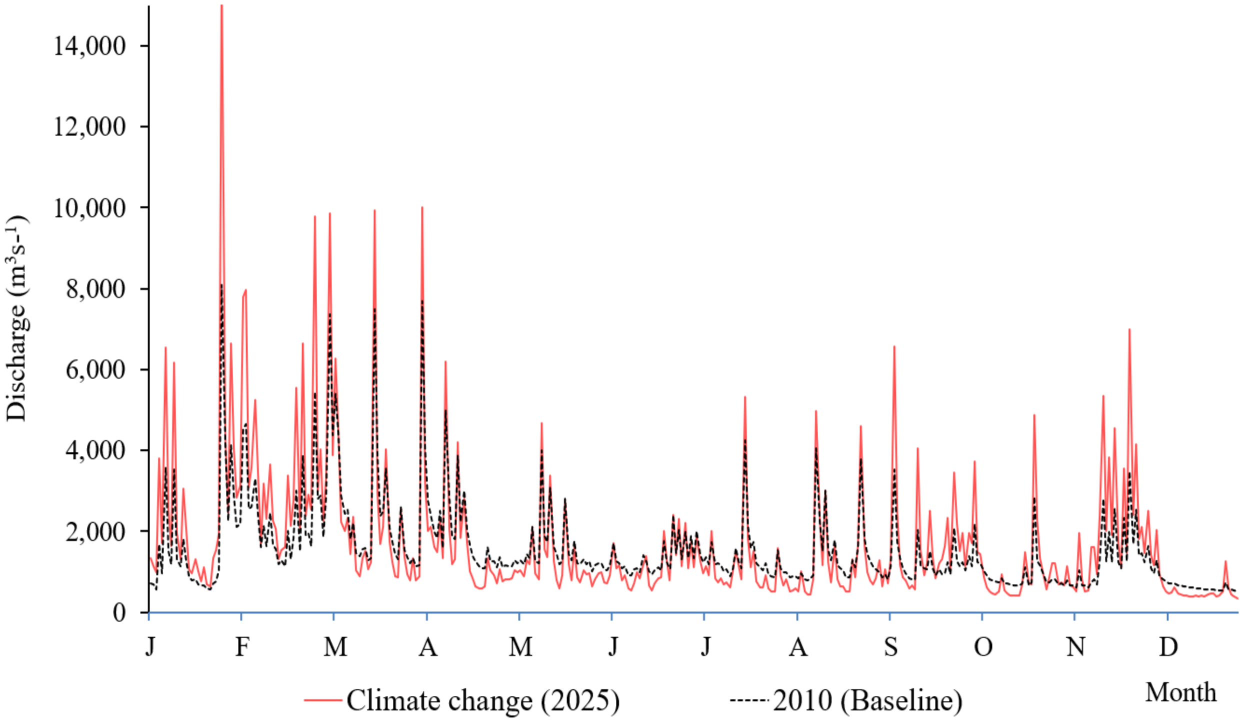

*Figure 6. Impact of the climate change on the streamflow fluctuation*

Tabel 4. Relative impact of change in climate and land use on the streamflow fluctuation

| **Streamflow characteristics** | **Baseline** | **Land use change** | | **Climate change** | | **Coupled change** | |
|---|---|---|---|---|---|---|---|
| | **$m^3s^{-1}$** | **$m^3s^{-1}$** | **Change (%)** | **$m^3s^{-1}$** | **Change (%)** | **$m^3s^{-1}$** | **Change (%)** |
| Min discharge | 523 | 313 | -40 | 355 | -32 | 270 | -48 |
| Max discharge | 8,100 | 13,400 | +65 | 15,880 | +96 | 17,530 | +116 |
| Mean | 1,556 | 1,554 | 0 | 1,738 | +12 | 1,851 | +20 |

### *3.4. Coupled Land-use and Climate Changes*

In this scenario we adjusted both climate and crop input parameter of the SWAT model simultaneously considering the climate change and the land use change in the previous sections. The coupled change in climate and land use sharply decreased the minimum discharge (48%) and increased the maximum peak discharge (116%, Table 4)).

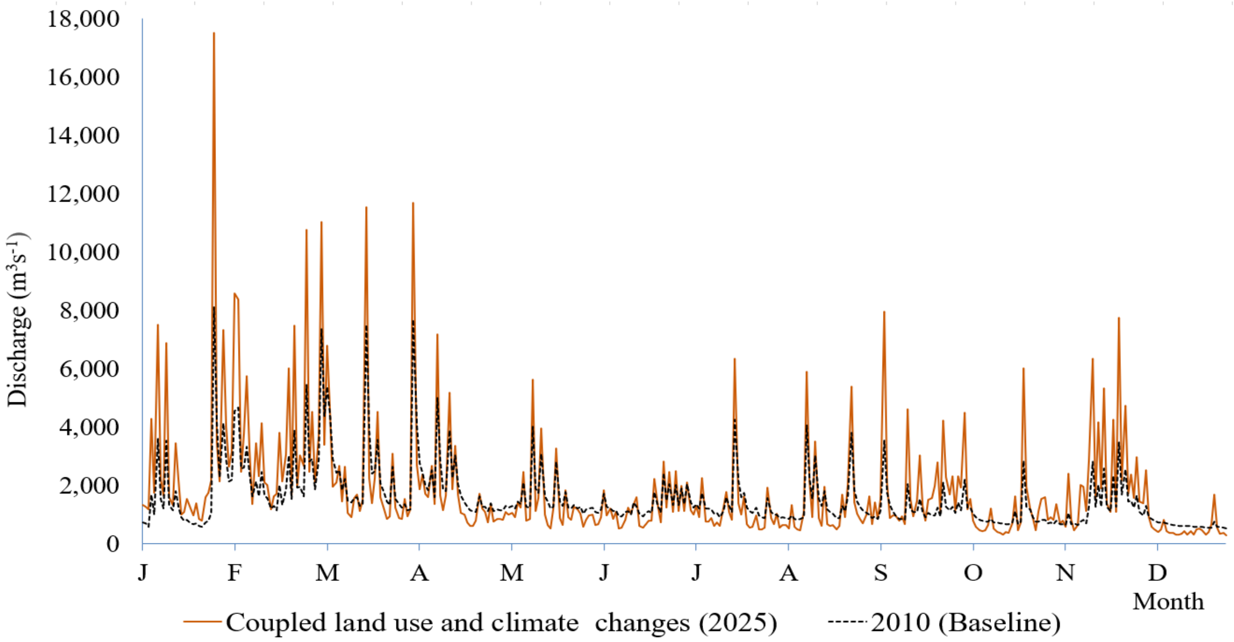

*Figure 7. Impact of the coupled land-use and climate changes streamflow fluctuation*

### *3.5 Relative Impact of Change in Climate and Land Use on The Stream Flow*

Both changes indicated significant impact on the extreme events such as maximum peak discharge and minimum discharge. The impact of the climate change on the increased peak discharge is more significant compared to that of land use change. Meanwhile, the impact of the land use change on the decreased minimum discharge is more significant compared to that of the climate change. Knowing relative contribution of the land use and the climate change on the future discharge fluctuation enables government and communities to select appropriate combination of mitigation and adaptation measure in Indonesia. As an example, to mitigate the decreased minimum discharge because of land use change, proper land use management such as sufficient proportion of protection forest areas in a river basin should be maintained. Forest land use has been identified by many researchers as the most effective land use in increasing water flow regulation of a watershed (Bruijnzeel, 1989; 2004). In addition to sufficient forest area in a watershed, effective soil and water conservation measures should be introduced in the agricultural area in a watershed (Tarigan et al., 2016b). The soil and water conservation measures increase water infiltration and reduces sediment flowing to the downstream reservoir. Both measures greatly enhance water security in the future. On the other hand, increased peak discharge because of the climate change is often better to adapt rather than to mitigate.

### *3.6. Comparison with Similar Studies in Other Regions*

Several other studies have reported the impact of changes in climate and land use. Most of these studies were carried out in China (arid-semi arid regions). Seven out of eleven reviewed studies showed that climate change have stronger impact on the streamflow than that of land use change (Table 5). Meanwhile, four reviewed studies showed that land use change have stronger impact. A study in Kenya showed that land use change had stronger impact than that of climate change. Relative impact of change in climate and land use are dependent on the type of climate zone and type of land use change. Deforestation and afforestation seem to be the type of land use change that affect streamflow more frequently. A watershed situated in arid-semi arid regions tends to be more sensitive to forest cover change. Deforestation or afforestation in drier regions (mean annual precipitation <1000 mm) was found to have greater impact on runoff than in wetter regions (Jackson et al., 2005).

Table 5. Review on the impact of changes in climate and land use on streamflow in other regions

| Authors | Location | Methods | Impact of changes in | | Human activities |
|---|---|---|---|---|---|
| | | | Climate | Human activity/ Land use change | |
| Ma et al., 2008 | Northwest China | Trend analysis | 64% decrease in streamflow | Limited | |
| Bao et al., 2012 | Northern China | Mann–Kendall test | 26 – 59 % decrease in streamflow | 42-74% decrease in streamflow | Afforestation |
| Khoi et al., 2014 | Be River, Vietnam | SWAT model | 26.3% increase in annual streamflow | 1.2% increase in annual streamflow | Deforestation |
| Li et al., 2014 | Northeast China | Mann-Kendall test | - | 70% decrease in streamflow | Deforestation |
| Li et al., 2009 | Loess Plateau of China | SWAT model | 95.8% decrease in streamflow | 9.6% decrease in streamflow | Expansion of grassland |
| Guo et al., 2016 | North western China | SWAT model | 102.8% increase in annual streamflow | 2.8% decrease in streamflow | |
| Mwangi et al., 2016 | Kenya | Mann-Kendall tests | 2.5% increase in annual streamflow | 97.5% increase in annual streamflow | Deforestation |
| He et al., 2013 | South China | | 45 % decrease in streamflow | 24 % increase in streamflow | Deforestation |
| Yang et al., 2017 | Northwest China | Hydrological modeling | 107% increase in streamflow | 7.3 % decrease in streamflow | |
| Xu et al., 2014 | Northwest China | | 26.9% decrease in streamflow | 73.1% decrease in streamflow | Deforestation |
| Zhang et al., 2016 | Northwest China | SWAT model | Strong increase in streamflow | slight reductions in streamflow | Expansion of grassland |
| Zheng et al., 2009 | Yellow River Basin | | 30% decrease in streamflow | 70% decrease in streamflow | |
| Zhang et al., 2008 | Loess Plateau, China | Mann-Kendall test | - | 50% reduction of annual streamflow . | |

## 4. Conclusion

We simulated future rainfall and temperature scenarios using the downscaled rainfall and mean surface temperature of 24 CMIP5 GCM outputs with moderate scenario of RCP4.5. For the 2025, the most considerable rainfall decrease is found in dry season, reaching almost 50% in August. Meanwhile, the median value of the temperature scenarios in 2025 is around 0.6 °C with the highest value projected by the model reaches 1.1 °C. We used distributed hydrologic model (SWAT) to simulate simultaneous impact of future changes in climate and land use change on the streamflow fluctuation. The SWAT model performed well with the Nash-Sutcliff efficiency values of 0.80-0.85, (calibration) and 0.84-0.86, (validation); and the PBIAS values ranges between -3 and 1.3 (calibration) and between 7.0 and 11.9 (validation). The coupled climate change and land use change decreased the minimum discharge 48 % and increased the maximum peak discharge 116% respectively. Separately, the land use change led to 40% decrease of the minimum discharge in dry season and 65% increase of the maximum peak discharge in wet season. Meanwhile, the climate change caused 32% decrease of the minimum discharge and 96% increase of the maximum peak discharge. Both changes indicated significant impact on the extreme events such as maximum peak discharge and minimum discharge. The impact of the climate change on the increased maximum peak discharge is more significant compared to that of land use change. Meanwhile, the impact of the land use change on the decrease of the minimum discharge is more significant compared to that of the climate change. The results of this study pointed out that the climate change and the land use change potentially become important drivers to the future discharge fluctuation Indonesia. The implementation of mitigation actions such as soil and water conservation in agriculture plantation to reduce the decrease of the minimum discharge during dry season and the adaptation measures for increased the maximum peak discharge during wet season are necessary.

## Acknowledgments

This study was funded by the Directorate General of Higher Education (DIKTI), Indonesia

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