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MODELLING OF HYDROLOGICAL RESPONSES IN THE UPPER CITARUM BASIN BASED ON THE SPATIAL PLAN OF WEST JAVA PROVINCE 2029 AND CLIMATE CHANGE

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ABSTRACT

In 2010, a spatial plan for West Java Province up to 2029 was published (*Perda* 22/2010). The purpose of the plan is to guide settlement area development. This study aims to assess the hydrological implications of the Spatial Plan 2029 within the Upper Citarum Basin (UCB) and with regard to climate change. A hydrological simulation based on land-use at the time of the plan (2010) and planned land use was performed using the JAMS/J2000 hydrological model. The settlement area from the spatial plan for 2029 was extracted and then superimposed onto the 2010 land use. Two different land-use scenarios (2010 and 2029) and a climate change scenario (1990-2030) were used for the hydrological simulation, with IPSL-CM4 and UKMO-HadCM3 being the products used for the latter. The simulation results were presented as river discharge and surface runoff. From the simulation results, the annual average of the simulated river discharge is expected to increase by 1.8% up to 2029 compared to the 2010 level. More substantial changes were noticed in the surface runoff, which is projected to increase on average by 8.9% annually due to the expansion of urban areas and agricultural land use. The seasonal analysis showed that river discharge and surface runoff both increased more markedly in the wet season. The study shows the potential of the JAMS/J2000 model to assess the impacts of land-use and climate change on hydrological dynamics.

Keywords: Climate change; Hydrological modelling; Land-use change; Spatial planning

1. INTRODUCTION

The combined effect of land cover and climate changes affects the hydrological regime (Giambelluca, 2015; Dwarakish & Ganasri, 2015). Climate change will have more influence on hydrological processes on a global scale, while on the regional scale (or smaller spatial scales), the impacts of land cover or land-use changes can be more critical (Giambelluca, 2015). The climate change factor is given more consideration in the projection of future hydrological dynamics (Kim et al., 2013).

In 2010, a spatial development plan for West Java Province up to 2029 was published (*Peraturan Daerah Nomor* 22 *Tahun* 2010). The primary purpose of the plan is guidance on settlement area development. Therefore, it is essential to identify the impacts of land-use changes on hydrological processes as a result of the implementation of the spatial plan, which

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can provide information for land-use planning.

Various researchers have studied the combined impacts of land-use change and climate change on hydrological responses (Julian et al., 2011; Marhaento et al., 2016). Based on Li et al. (2009), three major approaches can be implemented to assess these impacts, namely paired experimental catchments, statistical methods and hydrological modelling. In this study, in order to assess the hydrological effects of future land-use and climate changes, the JAMS/J2000 hydrological model (Krause, 2001; Kralisch et al. 2007) is applied. This model has been widely used for hydrological modelling studies, such as in the Kosi Basin, Himalayan Region (Nepal et al., 2014), the Vu Gia-Thu Bon Basin, Vietnam (Fink et al. 2013) and the Goksu Basin, Turkey (Donmez & Berberoglu, 2016). This study focuses on examining the impacts of the spatial development plan for West Java Province 2029 and future climate projections of hydrological dynamics in the Upper Citarum Basin (UCB) using the hydrological model. Julian et al. (2013) studied the initial set up of the J2000 model in a similar basin. The novelty of this study lies in the quantification of the combined impacts of the implementation of the spatial plan published by the local government and future climate projection, and their responses to several hydrological components.

2. MATERIALS AND METHODS

2.1. River Basin Characteristics

The study area is situated in the Upper Citarum Basin (UCB), Indonesia (Figure 1). The overall area of the basin is 1821 km², with elevations ranging from 667 to 2589 m. The Bandung Metropolitan Area is the main administrative region in UCB. With regard to changes in land-use conditions between the time of the plan (2010) and the time of its projections (2029), the level of partial imperviousness of the UCB is expected to double. Classification of land-use conditions at the time of the plan (2010) and those of the spatial plan will be discussed in the following section. In terms of climatological conditions, high precipitation occurs during the western monsoon (wet season) and low precipitation during the eastern monsoon (dry season). 70-80% of total annual precipitation generally occurs from November to April (wet season) (Julian et al., 2013). Between 1990 and 2009, annual precipitation ranged from 1688 mm to 2436 mm, with an average of 2036 mm, and mean air temperature ranged from 18.3°C to 31.8°C, with an average of 21.4°C.

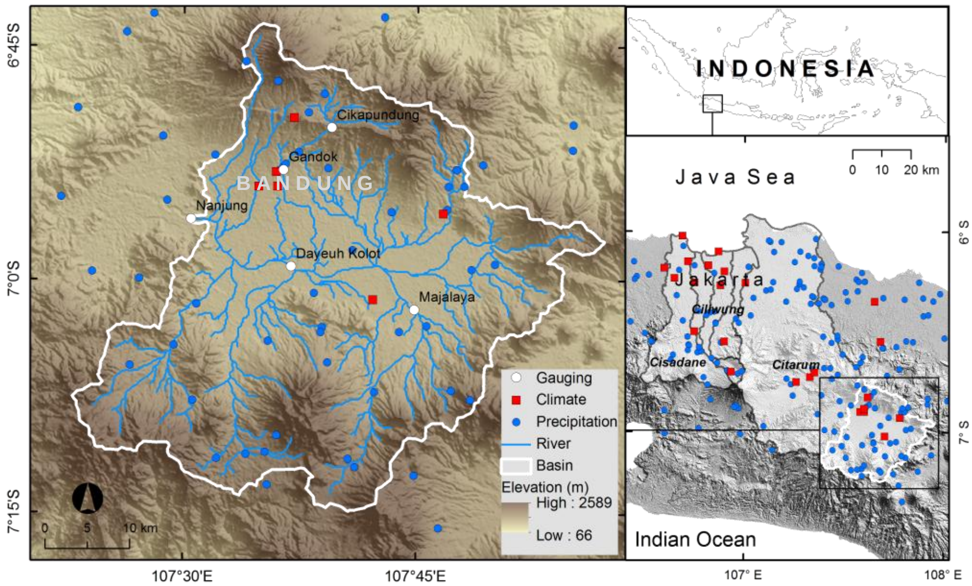


Figure 1 The Upper Citarum Basin

2.2. J2000 Hydrological Model

The JAMS/J2000 hydrological model comprises modules (e.g. Interception, Infiltration) and model parameters (e.g., *a_rain*, *MaxDPS*) (see Table 1 for all model parameters) to represent hydrological processes (Figure 2). The model requires climatological data (i.e. precipitation, air temperature, humidity, wind and sunshine duration), a topographic map, land-use map, soil and geological map, and validation data (i.e. observed discharge).

J2000 simulates four runoff components (*RD*1, *RD*2, *RG*1, *RG*2) originating from different sources. The runoff from sealed areas produces surface runoff (*RD*1); the excess of runoff from full capacity infiltrated soil (saturated soil); and surplus water from high precipitation, especially during the wet season. Interflow consists of slow direct runoff (Interflow I - *RD*2) and fast groundwater (Interflow II - *RG*1). *RD*2 originates from the interflow from the unsaturated soil zone or lateral outflow from large pore storage of the soil. The inflow forms *RG1* from the saturated weathering layer with high permeability. Baseflow (*RG*2) comes from the lower groundwater zone with long retention time.

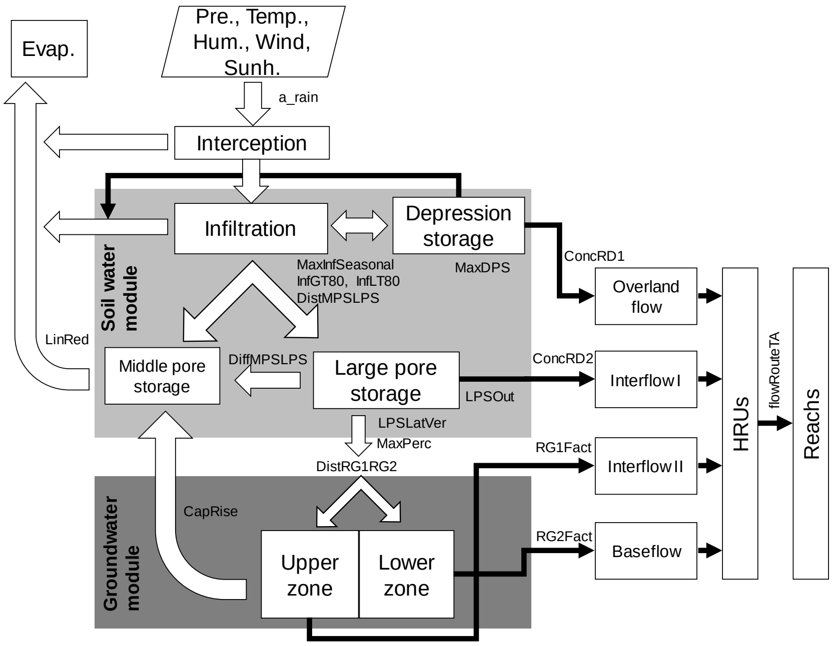


Figure 2 J2000 hydrological model concept (modified from Krause, 2001)

2.3. Data Collection and Preparation

Observed climate data were obtained from the Indonesian Meteorology, Climatology and Geophysics Agency and Central Agency for Water Resources, West Java (*Dinas Pusat Sumber Daya Air Jawa Barat).* For the climate scenario, the climate model from the World Climate Research Programme (WCRP) CMIP3 (Meehl et al., 2007) was used. These data were downscaled to a 0.5°×0.5° grid (Adam & Lettenmaier, 2003; Wood et al., 2004; Maurer et al., 2009). The IPSL-CM4 (Institut Pierre-Simon Laplace, France) and UKMO-HadCM3 (Met Office Hadley Centre, United Kingdom) with A1B scenario climate models were used in relation to the study period of 1990-2030. These are major climate models used in the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (2007) and also contribute to the IPCC fifth assessment report (2014). The A1B scenario has an equal emphasis on fossil intensive and non-fossil energy sources (Sheffield & Wood, 2008), while the A1 scenario family describes very rapid future economic and global population growth. The A1 scenario might be more suitable for urban area development (e.g., Bandung Metropolitan Area).

Land use in 2010 is represented as the 'current' scenario. Land-use information is used to compute the rate of interception of specific canopy and evapotranspiration in the soil water module. Topographic data were obtained from the Shuttle Radar Topography Mission (SRTM) Version 4.1. SRTM has a 90 m spatial grid resolution and 16 m vertical resolution, at a 90% confidence level (Rodriguez et al., 2006) and was used to generate elevation, slope, aspect and drainage models. A soil map was required to calculate the volume of large pore and middle pore storage. Geological data were used to estimate the storage capacity and retention coefficient of the groundwater areas. The observed discharge was measured at the Nanjung station, which is the ultimate discharge point from the overall study area (i.e., UCB) (see Figure 1). The observed discharge at Nanjung Station was used to calibrate and validate the model for the current scenario.

2.4. Spatial Plan of West Java Province 2029

A spatial plan of West Java Province for 2029 was published in the Local Regulation Number 22 year 2010 (*Peraturan Daerah Nomor* 22 *Tahun* 2010). The Spatial Plan 2029 has the purpose of maintaining forest cover of a minimum of 30% of the total catchment area and provides guidance on urban settlement area development. It is also employed in the preservation of water catchment areas to ensure the availability of water resources. For this study, we extracted the built-up area (rural and urban settlements) from the plan and then superimposed the other classes from the land use in 2010.

2.5. Modelling exercises

Model performance was tested using efficiency criteria, e.g., the Nash-Sutcliffe coefficient (E), E with logarithmic values ($\ln E$) for low flows, and percentage of bias (*PBIAS*), by comparing the observed discharge at Nanjung station and the simulated discharge output from the UCB. E focuses on the agreement of the peaks and high flows of the hydrograph.

During model calibration and validation, a split-sample approach was used. The available validation data (e.g., observed discharge) were split into two periods; the model was calibrated with period one, then validated with period two, and vice versa. A good model would show similar values for the efficiency criteria in both periods. In this study, the model was calibrated for the period 2005–2010, and validated for the period 2000–2005.

The trends in time-series data were assessed using the Sen method, and the significance of increasing or decreasing trends was tested using the Mann-Kendall method (Salami et al., 2014).

Implementation of hydrological simulations based on several scenarios was made using the calibrated model. The scenarios were distinguished based on the input of the different sets of climate and land-use data. They consisted of: (i) climate 1990-2009, land-use 2010; (ii) climate 1990–2009, Spatial Plan 2029; (iii) climate projection 2010-2030, land-use 2010; and (iv) climate projection 2010–2030, Spatial Plan 2029.

3. RESULTS AND DISCUSSION

3.1. Exploratory Data

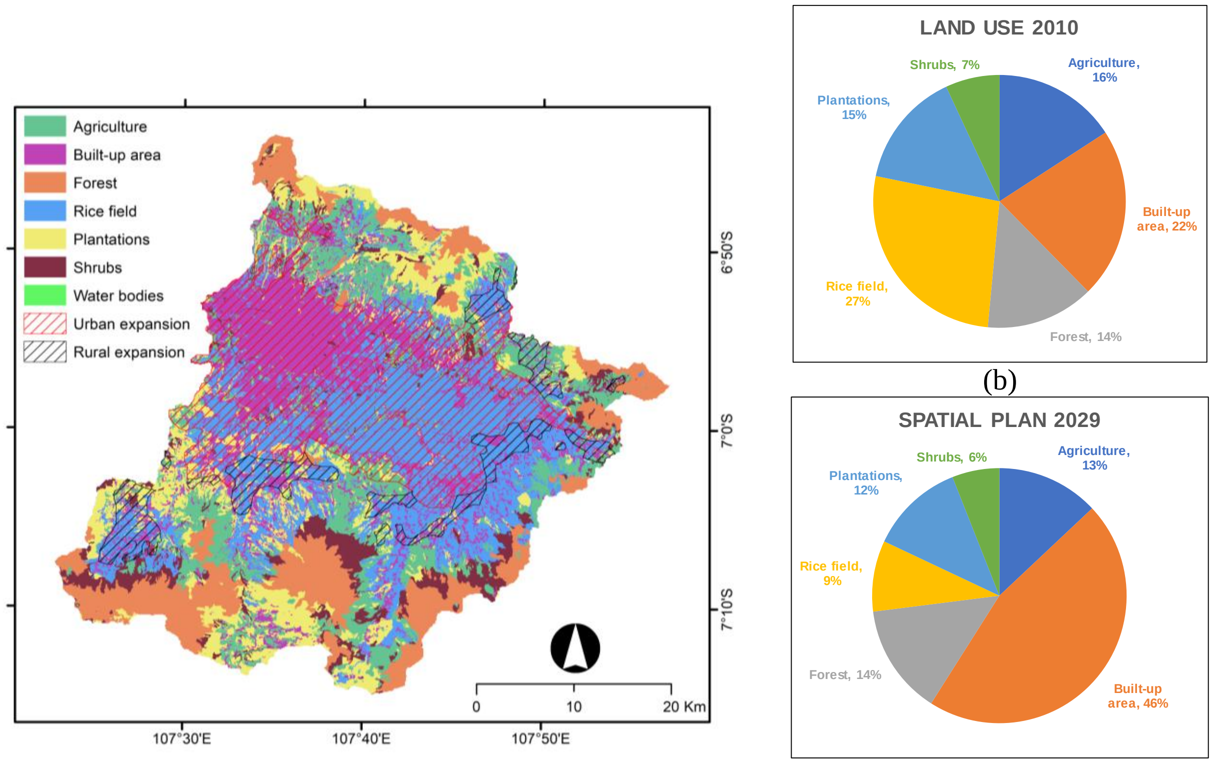
3.1.1. Climate

Before using the future climate model projections (e.g., IPSL-CM4 and UKMO-HadCM3) as input for the prediction of hydrological modelling, the historical climate models were compared with the historical observed climate data. Comparison between the precipitation model and the observed precipitation resulted in an 8% annual bias for the IPSL-CM4 model and 12% annual bias for the HadCM3 model. The annual temperature biases were +0.2°C for HadCM3 and +0.5°C for IPSL.

The future climate scenario was analysed in the UCB relative to the historical period from a similar climate model. There was an increase in the mean monthly average temperature of 0.36°C in the period 2010–2030 relative to the period 1990–2009. Precipitation increased by 25% from 2010 to 2030 relative to 1990–2009. The highest mean monthly increase was projected in December, and the beginning of the wet season was projected to begin earlier, in October.

3.1.2. Land-use and Spatial Plan

In 2010, land-use in the UCB was dominated by rice fields, at 27% (Figure 3). Vegetation and horticulture crops were classified as the agricultural area (16%), and tropical forests covered around 14%. The overall proportion of the built-up area was 22%. We assumed land use in 2010 to be the current situation. Based on the 2029 spatial plan relative to the current situation, the built-up area is planned to develop up to 46% of the total area (38% urban, 8% rural settlements) of the UCB. The expansion of the settlement areas will take place by buffering the land surrounding the current urban area (Bandung Metropolitan). The highest decrease was seen in rice fields (-17%). The forest cover area was maintained stable, at 14% of the total UCB.



(a) (c)

Figure 3 Expansion of the built-up area (urban and rural settlements) based on: (a) the spatial plan 2029 relative to land use in 2010; (b) Pie charts of the total area per land-use class [in %] for 2010; (c) land use and the 2029 spatial plan

3.2. Calibration of the J2000 Hydrological Model

Model performance in the calibration and validation periods resulted in *E* of 0.79 and 0.76, ln *E* of 0.89 and 0.84, and *PBIAS* of -1.4% and -1.1%. Peak flows during the wet season are able to be captured by the model (Figure 4). During the low flow months (July-September), the simulated discharges could capture the observed ones, as shown by the very high values of ln *E*. Based on Moriasi et al. (2007), *E* between 0.75 and 1.00 and *PBIAS* lower than ±10% demonstrates very good performance of the hydrological simulation.

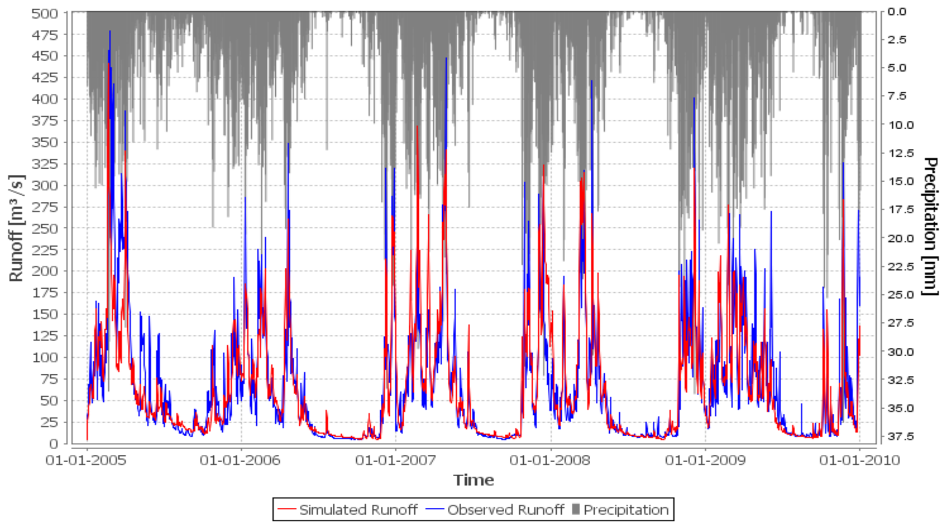


Figure 4 Calibration of the J2000 hydrological model (red line: simulated runoff; blue line: observed runoff; grey line: observed precipitation)

SoilConcRD1 (recession coefficient for surface runoff) and *MaxInfSeasonal* (maximum soil infiltration) in the wet season were observed to be the most sensitive parameters for *E*. This correlated to the amount of precipitation during the wet season being around 70–80% of total annual precipitation. The high sensitive parameter was also observed in *soilImGT80* (relative soil infiltration on the sealed urban area, with >80% sealing). This might be caused by 22% of the sealed (built-up) area in the UCB. All the effective model parameters for each process and the range of their values for calibration analysis purposes are presented in Table 1. The very sensitive parameter in *soilConcRD1* was in line with the sensitivity analysis results of Nepal et al. (2014) and Donmez and Berberoglu (2016).

3.3. Impact on Hydrology of the Spatial Plan of West Java Province 2029 and Climate Change

With a similar climate dataset (1990–2030), two different land-use scenarios (2010 and Spatial Plan 2029) were used for hydrological simulation. The results show that the annual average simulated discharge increased by 1.8% based on the Spatial Plan 2029 scenario compared to current land use. For the seasonal analysis, discharge increased by 2.1% in the wet season and 1.1% in the dry season. Simulated actual evapotranspiration (*AET*) in the spatial plan scenario changed on average by -2.1% annually (-5.1% in wet season; 0.2% in the dry season). The expansion of settlements causes a decrease in *AET* because there are fewer plants that transpire water. A significant change was noticed in surface runoff (*RD*1), with an average annual increase of 8.9% in the wet season and 9.2% in the dry season. The greater increase in surface runoff is due to the increases in urban and rural areas. Precipitation excess on the ground will easily become surface runoff because of the decreased infiltration caused by the increase in the impervious surface. This result is in line with Fohrer et al. (2001), who concluded that surface runoff was the most sensitive variable affected by the impact of land-use change. Prowse et al. (2006) also reported that the effects of built-up area expansion on hydrology were associated with a greater increase during the wet season than the dry. This is attributed to the decrease in the infiltration rate due to the increase in the impervious surface.

Trend testing was evaluated to assess the long-term trend rate of the projected discharge outputs (Table 2). The land-use scenario was assumed to be constant with the Spatial Plan 2029 from 1990 to 2030, 1990 to 2009 and 2010 to 2030. For all periods (1990 to 2030), all trends showed positive values for all model outputs (river discharge, actual evapotranspiration and surface runoff).

Table 1 Summary of the model parameters and range of their values for calibration analysis

Model parameter	Description [unit]	Calibrated value	Range
Interception module			
a_rain	Calibration for max. interception storage capacity per leaf area index (LAI) for rain [mm]	0.2	0.7-3.3
Soil water module			
soilMaxDPS	Max. depression storage capacity [mm]	2	0.1-6.5
soilLinRed	Linear reduction factor for evapotranspiration [-]	1.2	1-5
soilMaxInfSummer	Max. infiltration in summer [mm]	40	30-120
soilMaxInfWinter	Max. infiltration in winter [mm]	50	30-140
soilImpGT80	Rel. infiltration on sealed urban area (> 80% sealing) [-]	0.1	0.01-0.3
soilImpLT80	Rel. infiltration on less sealed urban area (< 80% sealing) [-]	0.5	0.1-1
soilDistMPSLPS	Distribution coeff. of infiltration into MPS and LPS [-]	0.2	0.1-1
soilDiffMPSLPS	Diffusion coeff. of water from LPS to MPS [-]	1	0.1-2
soilOutLPS	Coeff. of outflow from LPS [-]	2.2	0.1-5
soilLatVertLPS	Coeff. of outflow from LPS to lateral and vertical flow [-]	0.4	0.1-2
soilMaxPerc	Max. percolation rate (LPS to groundwater) [mm]	3	1-18
soilConcRD1	Recession coefficient for surface runoff [-]	1	0.1-3
soilConcRD2	Recession coefficient for interflow [-]	2	0.1-6
Groundwater module			
gwRG1RG2dist	Parameter for the flow to RG1 and RG2 [-]	0.1	0.01-4.5
gwRG1Fact	Parameter for adapting RG1 storage [-]	4	1-5
gwRG2Fact	Parameter for adapting RG2 storage [-]	1	1-4.5
gwCapRise	Parameter for capillary rise	0.01	0.001-1
Routing module			
flowRouteTA	Parameter for adapting flow velocity [-]	15	10-80

Significant increasing trends (at $\alpha = 0.05(^*)$) were found during the wet season for all model outputs. River discharge also showed a significant increasing trend in its annual value. The trend rate for the future period (2010–2030) seemed to be lower than in the previous two decades (1990–2009).

Table 2 Annual and seasonal trends (in mm/year) of selected model outputs for the periods 1990–2030, 1990–2009 and 2010–2030

Model output	Period	1990-2030	1990-2009	2010-2030
Discharge	Annual	6.2*	9	-4.2
	Wet season	9.0*	15.7	-11.2
	Dry season	2.2	11.9	-3.7
Actual evapotranspiration	Annual	0.3	6.4	-1.8
	Wet season	0.9*	1.5	0
	Dry season	0.3	6.4	-1.8
Surface runoff	Annual	1.2	5.9	-2.2
	Wet season	4.2*	5.6	-4.6
	Dry season	1.2	5.9	-2.2

The combined effects of the projected climate (2010-2030) and spatial plan 2029 on simulated discharge were also evaluated (Figure 5 and Table 3). By implementing the 2029 spatial plan in combination with future climate scenario, the projected discharge increased by +14% relative to the hypothetical current state scenario (land-use 2010 + climate 1990–2009). The increase was more marked during the wet season. The specific impact of the future climate projection

(2010–2030) will alter the seasonal pattern, making it more extreme during the wet season (November–April) and less so in the driest months (June–August) (see dashed line in Figure 5).

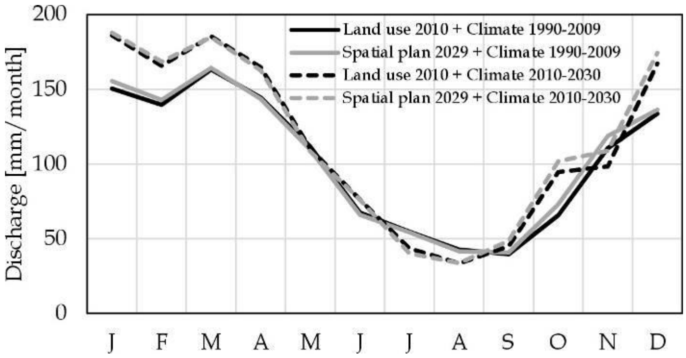


Figure 5 Comparison of mean monthly simulated discharge based on land use 2010, spatial plan 2029 and future climate projection

Table 3 Simulated discharge (in mm/month) based on land use 2010, spatial plan 2029 and future climate projection. The percentage values represent the relative change to the land-use 2010 + climate 1990–2009 scenario

Baseline	Period	Climate 1990-2009	Climate 2010-2030
Land use 2010	Wet season	140.3	161.2 [+15%]
	Dry season	63.6	67.2 [+6%]
Spatial plan 2029	Wet season	143.6 [+2%]	164.5 [+17%]
	Dry season	64.2 [+1%]	68.1 [+7%]

This study has demonstrated the utility of the JAMS/J2000 hydrological model to assess future spatial land-use planning and climate change projection on UCB hydrological dynamics. According to the hydrological model results, if the Spatial Plan of West Java Province for the year 2029 is implemented in the basin, it will lead to an increase in the annual discharge of 1.8% and surface runoff of 8.9%. This because of the double expansion of built-up areas. The ability of the hydrological model to quantify the potential hydrological response implication of the proposed spatial plans before their implementation offers spatial-plan decision-makers valuable knowledge to minimise the impact of water degradation and flood risk (McColl & Aggett, 2007; Guswa et al., 2014). These findings are potentially significant information for water and flood management in Bandung City in continuing to explore effective spatial plans.

4. CONCLUSION

The J2000 hydrological model was implemented to identify the potential impacts of the Spatial Plan of West Java Province for the year 2029 and a future climate change scenario on hydrological responses. The long-term trend of climatological dynamics was investigated as input for the hydrological simulation. Changes in precipitation were more predominant in the seasonal dynamics compared to the long-term trend (insignificant trend). The wet season becomes wetter and the dry season drier. The planned land-use changes, according to the spatial development plan, are expected to further enhance the seasonal changes on hydrological responses. The annual average simulated discharge would increase by 1.8% based on the Spatial Plan 2029 relative to the current land-use scenario (year 2010). The seasonal analysis showed an increase in river discharge of 2.1% in the wet season and 1.1% in the dry season. The more significant impacts on the UCB due to the spatial plan are predominantly changes in surface runoff of 8.9%/ 9.2%/8.7% in relation to annual average/wet season/dry season, mostly because of the significant reduction in infiltration due to the expansion of the built-up area. As demonstrated by the study, the JAMS/J2000 hydrological model can be used to explore the impacts of land-use change and climate change on hydrological dynamics, providing useful information for urban planning, environmental decision making, and water resource management.

5. ACKNOWLEDGEMENT

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