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Technical Paper

Impact of Land Use Change to Dependable Flow in Kuncir River, Nganjuk District, East Java

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Abstract

Currently, Kuncir River is a source of irrigation water in the southern of Nganjuk District. The potential of Kuncir River was assessed by measuring the dependable flow as an indicator of water supply for irrigated areas. The objective of this study was to estimate the river discharge and its dependable flow for irrigation from Kuncir River in Nganjuk District. River discharge data was collected from Kuncir River, rainfall data was collected from Nganjuk District, East Java and climate data was collected from climatology station of Badan Meteorologi Klimatologi dan Geofisika (BMKG) Sawahan, Nganjuk. There were two major steps on this study which were model development and model simulation using SWAT after calibration and validation. Model simulation showed NS value of 0.67 with mean daily flow of 7.15 m^3 s^{-1}*. Based on land use change scenario, the conversion of 50% on forest and 50% on range-grasses into agriculture land could increase 3.1% and 2.5% of average river discharge, respectively.*

Keywords: *Kuncir River, dependable flow, SWAT*

Abstrak

Sungai Kuncir merupakan sumber air irigasi di bagian selatan Kabupaten Nganjuk. Potensi Sungai Kuncir dapat dikaji melalui perhitungan debit andalan untuk dijadikan indikator jumlah pemenuhan air di daerah irigasi. Penelitian ini bertujuan menduga debit air sungai dan menghitung besar debit andalan untuk irigasi pada Sungai Kuncir, Kabupaten Nganjuk. Data debit sungai dikumpulkan langsung di Sungai Kuncir, data hujan dikumpulkan dari Dinas PU dan Pengairan Kabupaten Nganjuk, Jawa Timur, dan data iklim dikumpulkan dari stasiun kimatologi Badan Meteorologi Klimatologi dan Geofisika (BMKG) Sawahan, Nganjuk. Penelitian dilakukan melalui dua tahap, yaitu proses pembangunan model dan proses simulasi dengan SWAT setelah melalui proses kalibrasi dan validasi. Simulasi model memiliki nilai NS sebesar 0.67 dan debit rata-rata harian sebesar 7.15 m^3 s^{-1}. Skenario perubahan lahan menggambarkan konversi 50% lahan hutan dan 50% semak belukar menjadi lahan pertanian berpotensi meningkatkan nilai debit rata-rata Sungai Kuncir masing-masing sebesar 3.1% dan 2.5%.

Kata kunci: Sungai Kuncir, debit andalan, SWAT

Diterima: 22 Prebruari 2016; Disetujui: 04 April 2016

Introduction

Water shortages during dry season potentially decrease agricultural production in Indonesia. One of the affected areas is Nganjuk District located in the Eastern part of Java Island. Nganjuk District is a wide agricultural area and needs an efficient water management especially during dry season (Liyantono *et al*. 2013). Kuncir River is one of irrigation source located in Southern of Nganjuk District (Badan Perencanaan Pembangunan Daerah Kabupaten Nganjuk, 2012). This river recieves run-off, irrigation and domestic waste drain that flows into Brantas River where its water managed for agriculture, industry, tourism, mining, energy and water supply. The potency of Kuncir River can be assessed by measuring its dependable flow as an indicator of water supply to the community area.

Dependable flow is the total of the available flow to supply the water needs according to its probability. Dependable flow is measured to quantify the available planned flow of a river basin which is calculated on probability concept (Pereira *et al.* 1984).

Soil and Water Assessment Tool (SWAT) is a GIS tools based on spatially distributed watershed and that can be used to estimate impacts of watershed management on water flow, sediment and agricultural chemical yields of long periods in large ungagged basins (Arnold *et al.* 1998, Srinivasan *et al.* 1998). SWAT is based on physics, efficient on computations and capable to make long time simulations. Major components of SWAT are weather, hydrology, soil, plant growth, nutrients, pesticides and land management. Herewith, a watershed is divided into subwatersheds having unique soil/landuse characteristics which is called hydrologic response units (HRUs) (Arnold *et al.* 1998, Srinivasan *et al.* 1998).

The objective of this research is to estimate Kuncir River flow and to obtain the dependable flow for irrigation. To achieve this objective, a widely used parameters of SWAT was selected. The ability of SWAT to simulate various hydrological processes was also explored by applying different objective functions and statistical analysis.

Materials and Methods

Studied Area

Figure 1a shows Kuncir River Sub-Basin, Nganjuk District, East Java. Kuncir River is located on the Southern part of Nganjuk District (Fig.1b). The outlet for this study was chosen based on the monitoring points on the field observation, located at 7.672 °S and 111.843 °E covering an area of 96.29 km^2. The river flows into the Brantas River. The covered area is predominated by flat lowland in the northern parts and mountains in the southern parts. The elevation varies from 75 to 2535 m.

Data Source and Description

Digital Elevation Model (DEM) was derived from Indonesia Elevation Map (Peta Kontur Rupa Bumi Indonesia) 2001. Daily weather data (temperature, precipitation, wind speed, radiation and humidity) was collected from climatology station of Badan Meteorologi Klimatologi dan Geofisika (BMKG) Sawahan located in the watershed (Fig.1b). Precipitation data was collected from Public Works and Irrigation Services Nganjuk District. The climate data ranged from 2010 to 2013 which matched with the period of field observation. Land use was derived from Peta Rupa Bumi Indonesia (RBI) of Nganjuk District with scale 1:25,000. Soil type was derived from landsystem map of Java Island with scale 1:250,000. Three soil classes were found in studied area which was differed by the soil texture and drainage type. There were 3 hydrology classes, type A, B and D. Daily discharge for the period of 2010 to 2013 was used to calibrate and validate SWAT.

Modeling Process

Modeling process was divided into two big steps: data preparation and model simulation. Inputted data for the sub-basin was prepared and followed by: (i) watershed delineation and derivation of sub-basin characteristization, (ii) hydrological response unit definition, (iii) model running and parameter sensitivity analysis, and (iv) calibration and validation of the model including uncertainty analysis. Model results considered acceptable if coefficient of determination (R^2) greater than 0.5. If R^2 <0.5, calibration and validation then performed using Nash-Sutcliffe (NS) efficiency model to known how well the plot of observed versus simulated value fits the 1:1 line. The model was satisfactory if NS reach 0.5 and R^2 >0.5 (Moriasi *et al.* 2007, Santi *et al.* 2001). Another step was calculated the dependable flow using Weibull method after validation the model.

The total precipitation (PRECIP) was the major inflow component, whereas the actual

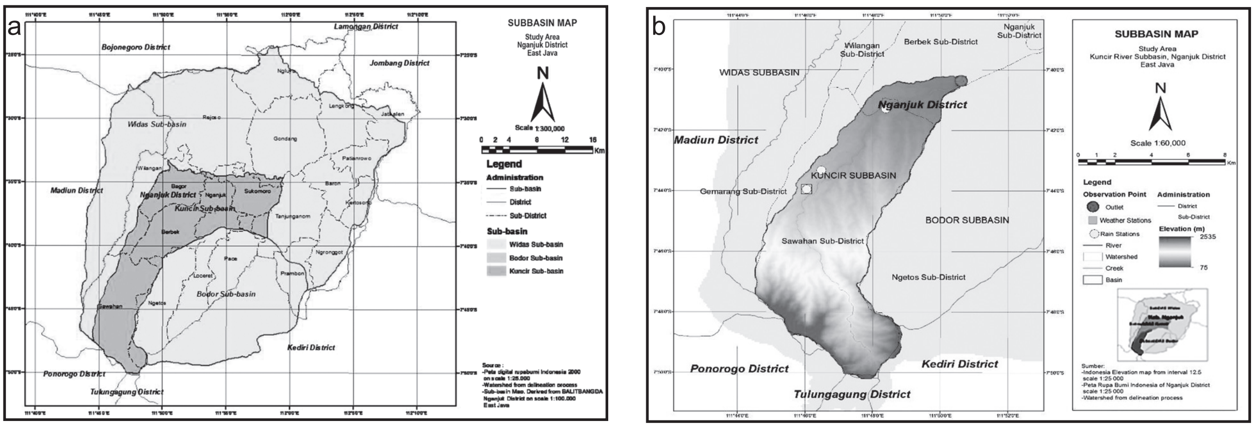

Figure 1. Location of basin and sub-basins (a) and elevation of Kuncir River Sub-basin in Nganjuk District, East Java (b).

Table 1. Selected hydrologic parameters for sensitivity analysis.

Parameter	Process	Rank	Variation range	Fitted value
Effective hydraulic conductivity in main channel alluvium (CH_K2 in mm h^{-1})	Channel flow	1	0 - 150	0.160
SCS curve number (CN2)	Runoff	2	±25%	0.196
Base flow recession constant (ALPHA_BF in days)	Groundwater	3	0 - 1	0.510
Surface runoff lag coefficient (SURLAG)	Groundwater	4	0 - 10	0.129
Manning`s roughness coefficient for main channel (CH_N2)	Channel flow	5	0 - 1	0.313

evapotranspiration (ET) and the basin water yield (WYLD) were the major outflow components. The WYLD in the SWAT model is defined as the summation of the surface water flow (Q_{surf}), the water that enters the stream from soil profile as lateral flow contribution (Q_{lat}) and the water that returns to the stream from the shallow aquifer also known as groundwater contribution (Q_{gw}) minus the total loss of water from the tributary channels as a transmission through the bed and finally reach the shallow aquifer as recharge. Another component was the percolation below the root zone commonly called groundwater recharge (PERC), which could be an inflow for flow at downstream of the subbasins. The water that remains in the soil profile of each subbasin is then considered as the soil water (SW) remaining at the end of the period.

Landuse Scenario

Land use change scenario was developed to know the impact sensitivity of land use change on Kuncir River flow. Land use change is tending to agricultural land because majority people in this area are farmer. These scenarios were:

1. Partial Deforestation to Agriculture (PFA). This scenario manipulates the forest land cover by decrease 50% of forest area and convert it to agricultural land.
2. Partial Range-Grasses to Agriculture (PRA). This scenario manipulates the range-grasses land cover by decrease 50% of range-grasses area and convert it to agricultural land.

Model Calibration

After the first run (simulation) of the model, the responsiveness of different parameters was identified through sensitivity analysis. There were 4 (four) sensitive parameters to get high accuracy of predicted flow: SCS-Curve Number (CN2), available groundwater capacity (SOL_AWC), evaporation compensation factor (ESCO) and alpha base flow recession factor (ALPHA_BF) (Ferijal 2012). Since every basin have different characteristic, the sensitivity analysis was performed to define the rank of the most sensitive parameter on predicted flow. The fine tuning of the sensitive parameters then resulted in ranked outputs that show how the catchment behaves under the given conditions (see Table 1).

Model calibration of SWAT model can be performed automatically by comparing the observed flow and predicted flow. The observed data was daily flow for 2010-2013 period obtained from Kuncir monotoring station. Statistic indicators used for calibration was coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NS) such as recommended by The American of Civil Engineers (Ahl *et al*. 2008).

Model Validation

The validation of the model was performed using flowdata at Kuncir monitoring station. Observed flow then compared with the calibrated flow resulted from SWAT model. The comparison between the calibrated flow and observed flow was done using NS model. Modeling process will be continue if NS is on the satisfied category (NS >0.5) and validated with R^2 factor (>0.5) (Moriasi *et al.* 2007).

Results and Discussion

Parameter Sensitivity Analysis and Calibration Model

The Results from the sensitivity analysis in form of hydrological parameter (see Table 1) showed different responses and the most sensitive parameters on the output flow. The parameters were ranked from the highest impact on simulation and changed through the calibration process. For example, CN2 before the analysis was 15 and after the analysis was performed, it changed to 0.196.

Sensitivity analysis result for 2010-2013 period shows the model had higher ranges than the observed flow with NS -1.09 and R^2 0.40. The averaged value of observed data was 6.93 $m^3 s^{-1}$ and model data was 6.67 $m^3 s^{-1}$. The daily average was relatively similar between observed and model data though NS value was categorized here as poor caused by the uncalibrated parameters that could

Table 2. Annual water balance components at Kuncir outlet (all values are in millimetres of water).

Year	PRECIP	ET	Q_{lat}	Q_{surf}	Q_{gw}	WYLD	PERC	SW
2010	5443.90	1541.68	1261.26	1916.47	205.11	3375.94	494.04	49.70
2011	3194.10	954.95	754.96	1262.10	168.62	2180.32	291.48	45.63
2012	2608.60	937.42	631.61	840.27	101.64	1568.70	229.73	43.15
2013	3800.00	1244.24	945.68	1236.72	175.98	2351.49	360.92	29.25

Table 3. Water balance components at Kuncir outlet for land use change scenario.

Scenario	Q_{ave} (m3 s^{-1})	Q_{lat} (mm yr^{-1})	Q_{surf} (mm yr^{-1})	Q_{gw} (mm yr^{-1})	WYLD (mm yr^{-1})	PERC (mm yr^{-1})
Control	7.15	898.38	1313.89	162.84	2369.11	344.04
PFA	7.37	744.82	1565.85	119.23	2423.91	264.89
PRA	7.33	778.09	1477.25	162.84	2412.21	330.58

underestimate the observed flow. The averaged flow for the auto-calibration model was 7.15 m^3 s^{-1} with NS 0.67 and R^2 0.67 that shows better performance based on the recommendation from previous experiments (Santhi *et al*. 2001, Moriasi *et al*. 2007, Fiseha *et al*. 2012).

Time series of precipitation shows similar fluctuations with weir discharge (Fig.2). The lower discharge on June to November (dry season period) related to the precipitation data. Water discharge is affected by many factors but among these factors, rainfall and land use are the two most often researched (Wei *et al*. 2007). This condition occurred because the rain intensity and duration, which affect the amount of infiltration, groundwater and surface flow (Muchtar and Abdullah 2007).

Water Balance

The annual water balance for the entire subbasin is shown in Table 2. The total precipitation (PRECIP) was the major inflow component, whereas the actual evapotranspiration (ET) and the basin water yield (WYLD) were the major outflow components. The maximum value of WYLD occurred in 2010, and minimum in 2012. WYLD is highly affected by Q_{lat} and Q_{surf}, contrast with Q_{gw} and T_{Loss} which have smaller impact on WYLD changes. In 2010 and 2012, Q_{lat} were 37.36% and 40.26%, Q_{surf} 56.77% and 53.56%, SW 49.70 mm and 43.15 mm.

In the period of 2010-2013, precipitation was high throughout the years. The increase of precipitation is associated with hydrological components, and influences WYLD. Maximum WYLD is related to groundwater flow. One of factors affects the groundwater contribution according to Fiseha *et al*. (2012) is the land cover characteristic was dominated by agriculture and mixed urban areas that can potentially minimize the infiltration potential of the soil and increase runoff coefficient. The lower contribution of surface flow is disagree with Fiseha *et al*. (2012) and NJIT (2010). The possible factors to affect the surface flow are: the dominance of soil characteristics, soil water and temporal distribution of precipitation.

Dependable Flow

Dependable flow resulted from model has similar shape with the observed data (Fig.3). Dependable flow was derived from monthly mean flow of the observed data on 80% probability for 2010-2013 periods. Previous experiments by Indarto *et al*. 2012 and Indra 2012 stated that dependable flow was the minimum discharge on a probability used to calculate the planned flow from a water source.

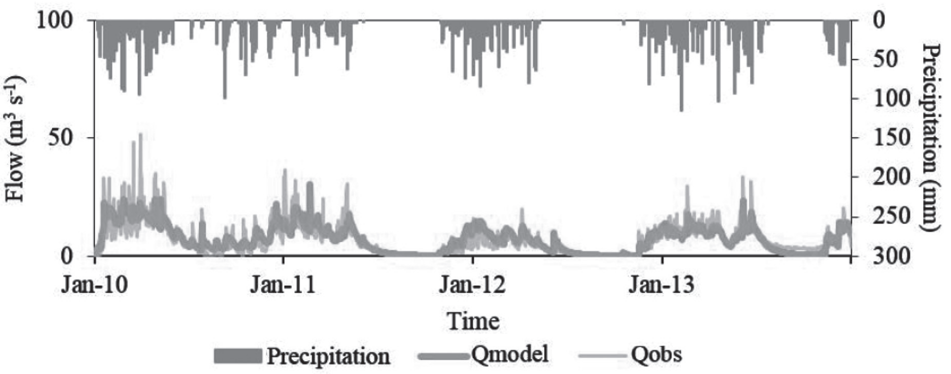

Figure 2. Auto-calibration results for daily flow at Kuncir outlet (2010-2013).

It means that 80% probability is only 80% of the minimum water discharge to be supplied for the area.

Flow duration curve (FDC) which was calculated in logarithmic scale (Fig.4) shows the model performes well with the observed data. FDC was made by ranking the highest value of data to the lowest value of data. Probability was then given to according the rank and then plotted with the water discharge. Logarithmic FDC performs well and produces globally less biased estimates than linear FDC. The raw data was logarithmically transformed to avoid negative estimates. The advantage in applying this method is that it keeps most of the dataset variance in a limited number of shape functions and to reduce the influence of the largest observed values (Sauquet and Catalogne 2011).

FDC divided the dependable flow into 3 groups: Q_0-Q_{10} for high flow, Q20-Q60 for medium flow and Q_{70}-Q_{100} for low flow. Q_{10} in FDC has the high flow (14.90 m^3 s^{-1}) meaning that this flow has low proportion (10%) on 2010-2013 period. Q_{100} has the lowest flow (0.13 m^3 s^{-1}) which can be considered as the minimum flow in Kuncir River. Mohamoud (2008) described furthermore the three categories of water (river) flow. High flow primarily occurs because of the intense storm rain. Medium flow is variated in every region, depended on dryness indexs, elevation proportion and percentage of soil water. Low flow is depended on dryness index and available water capacity ration in every layer of soil.

Impact of Land Use Change on Water Flow

Simulation in land use change scenario indicates an increase of river discharge (Fig.5) and is also visualized in FDC (Fig.6). PFA converts 50% on forest (approximately 17.58% of watershed area) into agricultural land. This scenario resulted in higher average of water discharge (7.37 m^3 s^{-1}) than the control simulation. Water balance components of PFA on Table 3 also have an increase of surface water contribution and water yield for 19.17% and 2.31% and the decrease of lateral and base flow contribution of 17.09% and 26.78%. A total of 50% of range-grasses field (approximately 12.8% of watershed area) is converted to agricultural field in PRA scenario. Daily mean flow in PRA is 7.33 m^3 s^{-1} and shows the increase of water discharge on control simulation. Similar to PFA, water yield is also increased by 1.82%. Higher contribution is showed by surface flow (12.43%) and lower contribution is showed by lateral flow (13.39%).

Model simulation for both scenarios indicates an increase on Kuncir River flow as well as the increase of conversion of forest and range-grasses. FDC shows that both scenarios have different response to probability of exceedance. PRA in 10% probability have the higher dependable flow. Otherwise, PFA and control have lower dependable flow. Three experiments have similar water discharge (~19.18 m^3 s^{-1}) in 2% probability of exceedance. Different response is showed by PRA and PFA on 80% probability of exceedance. PRA have lower water discharge (under control simulation) of 1.16 m^3 s^{-1} and PFA have higher water discharge (above control simulation) of 1.26 m^3 s^{-1}. Although water discharge was increased, the increasing is small. Based on the model, forest, range-grasses, and agricultural land cover were almost have same impact to dependable flow.

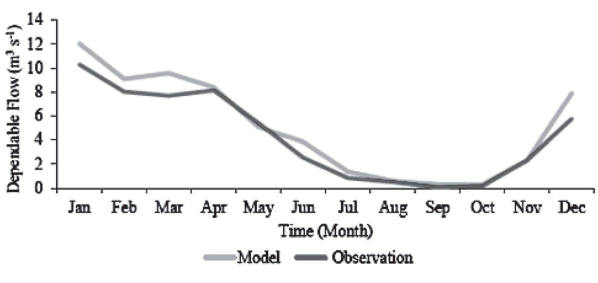

Figure 3. Monthly dependable flow from period 2010-2013 on 80% probability.

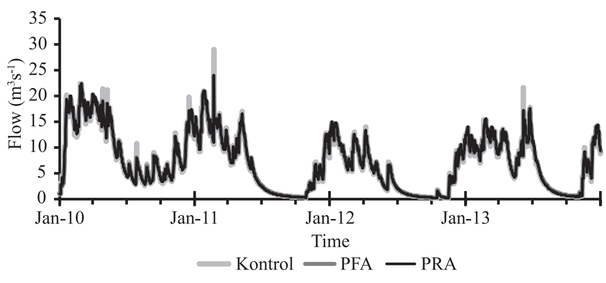

Figure 5. Daily water flow resulted from two land use change simulations.

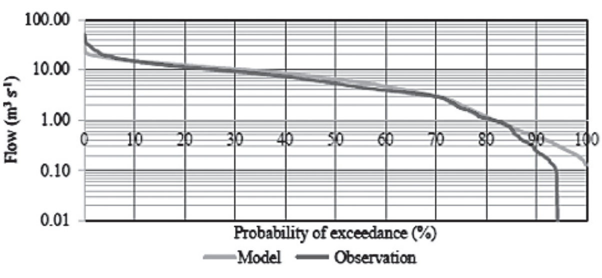

Figure 4. Flow duration curves for Kuncir outlet.

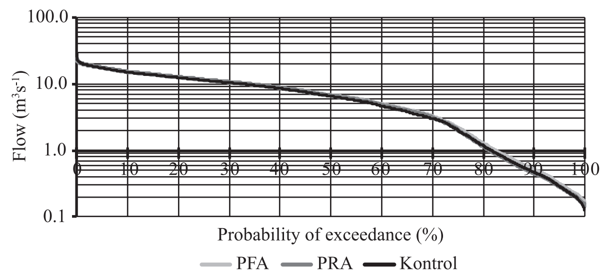

Figure 6. Flow duration curves for Kuncir outlet for two land use change scenario.

Conclusion

SWAT model has been succeed to calibrate and validate in the study area, which located in Kuncir River Subbasin, Nganjuk District, using time series data of precipitation and water discharge. Model simulation is well correlated with observed flow with NS 0.67. Average flow of model simulation is 7.15 m^3 s^{-1}, very close to actual average of observation flow (6.93 m^3 s^{-1}). Water balance components analysis showed that precipitation is highly related to water yield, which affects the river flow. High correlation between model and observed flow is also showed by FDC, which explains the river flow on probability of exceedance in a period of time. FDC is derived from dependable flow analysis on 80% probability. Land use change scenario draws the sensitivity of Kuncir River flow on land conversion very well. The conversion of forest and range-grasses into agricultural land is potentially less increasing the water discharge of Kuncir River.

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