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Annual and Seasonal Discharge Responses to Forest/Land Cover Changes and Climate Variations in Kapuas River Basin, Indonesia

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Abstract

Kapuas River basin is one of the most important natural water resources in West Kalimantan, Indonesia. However, rapid increasing of forest degradation and land cover changes in the basin and climate variations has decreased the capability of the basin to provide and maintain its functions especially as a water catchment area. Examining the impact of land cover changes and climate variations is required to identify how the on-going and possible land cover and climate change may influence the annual and seasonal discharge, which later can be used to improve the predictability of hydrological consequences in the basin. Large scale of forest degradation and land cover changes had occurred in Kapuas River basin in the period of 1996 to 2006. More than 4,748 km^2 (18.9%) of primary dryland forest turned into logged-over forest and around 5,473 km^2 (99.1%) of primary swamp forest has been degraded. Hydrological simulation result on August 1997 and December 2007 which represent strong El Niño and La Niña, respectively, shows that the absence of forest cover reduced the discharge up to 15.8% and 38.6% in dry season, and increased the discharge up

to 7.0% and 12.5% in wet season. Results of hydrological simulation scenarios revealed that forest degradation and land cover changes affect Kapuas River discharge behavior, even though climate variations are the main factors that contributed to the change of the discharge in both annual and seasonal patterns.

1. Introduction

Kapuas River basin is one of the most important natural water resources in West Kalimantan, Indonesia. Almost 23 percentages of households in West Kalimantan are still using river water for drinking and other daily needs and highly depend on water catchment capability of the basin (BPS Kalimantan Barat, 2008). Kapuas River is also used as main transportation access to reach several remote areas which lack of inland transportation facilities, therefore stable and sufficient river depth is desirable.

However, forest areas in West Kalimantan are under threat of being lost and fragmented due to over utilization of plants and ecosystem. Illegal logging, forest fire and forest conversion have caused many environmental problems particularly in Kapuas River basin which is the main water catchment area and a vital water resource in West Kalimantan. It has long been known that forest is a vital factor for maintaining and improving environmental quality by its contribution such as the provision of clean water for housing, industry and irrigation, and the capacity to reduce sedimentation and erosion. Removal of forest cover causes alteration of the hydrological cycle, mainly by eliminating evapotranspiration and redistributing and modifying the amount of rainfall that reaches the ground (Wright et al., 1990).

Only a few studies evaluated the effect of land/forest cover change in Kapuas River basin have hitherto been done/published. Lusiana et al. (2008) studied the impact of forest cover changes using GenRiver model in Sibau Hulu and Datah Dian village, a small water catchment area in the upstream of Kapuas River basin. They found that converting all forest that still exist (80% for Sibau Hulu and 40% for Datah Dian) into degraded land will increase runoff by 50% and 30% for Sibau Hulu and Datah Dian, respectively. However, the seasonal variations of river runoff in that catchment still remain unclear.

Furthermore, since condition of "too much and too little water" appear following the rapid loss of good forest cover and climate variations in the basin, examining the impact of land cover changes and climate variations are required to identify on how the on-going and possible land cover and climate change may have influence to the annual and seasonal discharge and improve the predictability of hydrological consequences. The objectives of this study are: 1) to analyze forest and land cover changes in Kapuas River basin in the period of 1996 to 2006, and 2) to analyze the impact and sensitivity of forest/land cover changes as well as climate variability to river discharge in Kapuas River basin through hydrological modeling.

2. Study site

Kapuas River is the largest river in West Kalimantan and considered as the longest river in Indonesia which has about 1,086 kilometers length. Along 942 kilometers of the Kapuas River is possible to use for waterway transportation. Kapuas River basin covers an area about 82.8 thousands km^2 or 55% of West Kalimantan area and is located in the north east of West Kalimantan and geographically lies between 1° 35' 38" north - 1° 19' 19" south and 109° 40' 27" - 114° 12' 50" east (Figure 1). Based on its specific geographical position, Kapuas River basin area is passed by Equator line. Because of this situation, Kapuas River basin is one of the tropical areas with high air temperature and also high humidity. The topography of Kapuas River basin encompasses plain, hill and mountainous areas, with elevation ranging from about 0.5 meter to more than 2,360 meter above sea level.

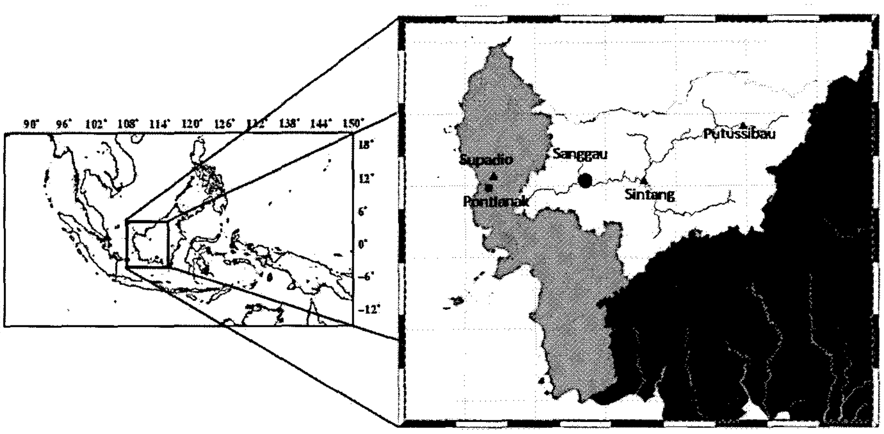

Figure 1: Location of Kapuas River basin and the three meteorological stations in Supadio, Sintang and Putussibau that are used in this study.

About 55.3 thousands km² of Kapuas River basin was designated as forest area or 66.7 % of the whole basin area. However, forest coverage particularly primary forest in the basin tends to reduce year by year, and in 2006 the primary forest coverage was only 19.35 thousands km² (23.34 % of basin area). High logging activity (legal and illegal), forest conversion and forest fire are considered as the main factors of forest degradation in the basin.

Kapuas River originates in the mountains of Kapuas Hulu near the border with Sarawak, Malaysia, and flows west. It empties into the South China Sea about 20 km south of the city of Pontianak. The river drains the extensive Danau Sentarum area, an extensive protected reserve of wetlands and freshwater lakes, and intermittently flooded forest. The river is an essential transportation corridor in West Kalimantan. Besides been used for access to settlements along the river, it is also used for transportation of timber out of the island's interior.

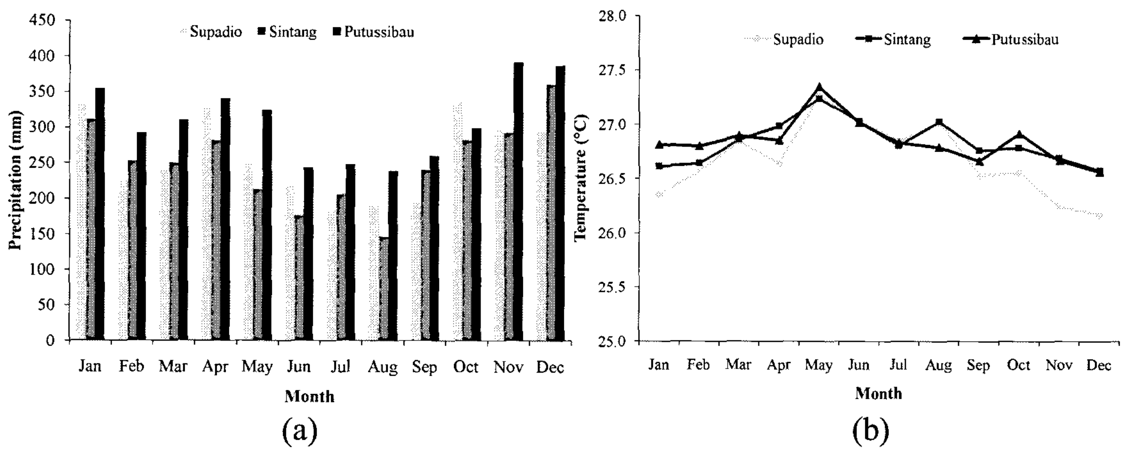

Figure 2: (a) Mean monthly precipitation, and (b) mean monthly average temperature in Supadio, Sintang and Putussibau meteorological stations between 1997 and 2007.

The basin has a tropical humid climate which is characterized by two seasons, dry and rainy/wet seasons. The monsoon type climate changes approximately every six months, where the dry season is from May to October and the rainy/wet season from November to April. Based on rainfall data from three weather stations (Supadio, Sintang and Putussibau) in 1997 to 2007, the annual rainfall in Kapuas River basin was high, varying between 2,500 to 4,500 mm/year with an average of 3,088, 3,011 and 3,685 mm/year in Supadio, Sintang and Putussibau. The pattern of average monthly rainfall also shows that Kapuas River basin was relatively wet throughout the year, with the comparatively high monthly rainfall in November to April while the low monthly rainfall occurred in June, July and August (Figure 2a). The monthly average air temperature ranged from 26.2-27.3°C with the highest temperature occurred in May and the lowest average temperature occurred in December (Figure 2b).

3. Research methodologies and data

This research is divided into two main phases. The first phase is to analyze forest and land cover changes in Kapuas River basin and the second phase is to simulate and evaluate the impact of forest/land cover and climate changes on Kapuas River discharge.

3.1. Land cover change analysis

Land cover change in Kapuas River basin is analyzed by using ArcGIS software version 9.2 and ArcView 3.3. Three land cover maps which cover the whole West Kalimantan area in 1996, 2000 and 2006 are used in this study. These land cover maps are obtained from Indonesia Ministry of Forestry. Since land cover change analysis will be focused only in Kapuas River basin area, the existing West Kalimantan land cover maps are overlaid and intersected with the Kapuas River basin boundaries to get only the land cover map of Kapuas River basin area. These "new" land cover maps are used to calculate and analyze the changes of land cover from 1996 to 2000 and from 2000 to 2006 using ArcGIS and ArcView. Some of hotspot and forest concessionaire data in West Kalimantan are also used for further analysis.

3.2. Impact of land cover and climate changes to Kapuas River discharge/runoff

In this study, the Hydrological Simulation Program-Fortran (HSPF) is used to perform hydrological simulation. At first, the hydrological model is used individually to simulate the hydrological responses to land cover and climate change in the basin by using observation data. Second step is to assess and improve the previous simulation.

HSPF is a comprehensive watershed simulation model developed by United States Environmental Protection Agency (US EPA) designed to simulate all the water quantity and quality processes that occur in a watershed, including sediment transport and movement of contaminants. It can reproduce spatial variability by dividing the basin into hydrological homogenous land segments and simulating runoff for each land segment, independently, using different meteorological input data and watershed parameters (Bicknell et al., 2001).

In this simulation, four primary tools are used to supports the hydrological modeling efforts:

(1) Watershed Modeling System (WMS) for basin delineation, importing land use and segmentation, defining segment parameters, developing reach segment parameters, defining meteorological input time series data, and entering mass links to define transformations from basin to reach to develop an HSPF User Control Input (UCI) file.

(2) Watershed Data Management Utility (WDMUtil) for storing/importing the available meteorological data into WDM files and perform operation necessary (e.g., computing, editing, aggregating/disaggregating, filling missing data, etc) in order to create the input time series data for HSPF simulation.

(3) WinHSPF for run the Hydrological Simulation

(4) Scenario generator (GenScn) for comparing and analyzing the HSPF simulation result in hydrology calibration process

An HSPF simulation is created by combining basin data sets, land use, and meteorological data sets and saved as*. UCI in a text format.

3.2.1. Digital Elevation Model (DEM) data and basin delineation

To delineate Kapuas River basin area, the 90-meter resolution DEM (Digital Elevation Model) data from HydroSHEDS (Hydrological Data and Maps Based on Shuttle Elevation Derivatives at Multiple Scale) which is obtained from United States Geological Survey Earth Resources Observation and Science Data Center (http://hydrosheds.cr.usgs.gov.) is used. The delineation of Kapuas River basin is obtained from this dataset using Watershed Modeling System (WMS) version 7.0.

The Topographic Parameterization program (TOPAZ) which is embedded in WMS program, is used for computing flow path/directions and flow accumulations. With the aid of the flow accumulations, the location of basin outlet is determined and the stream networks will be created. Using the outlets on the stream network and the flow directions and accumulation, the basin boundaries are created and converted into polygon. After the boundaries and polygon of the basin/sub-basins have been determined, geometric properties which is important for hydrological modeling (area, slopes, runoff distances, etc.) are computed. The land cover/land use data will be superimposed and the basin/sub basins will be divided into hydrologically similar segments (e.g. forest area, settlement, agricultural area, etc.).

3.2.2. Model calibration and sensitivity analysis

The purpose of calibration is to adjust the model so that the simulated flow is similar to the observed flow data as closely as possible. The calibration procedure typically involves a sensitivity analysis to identify key parameters and parameter precision required for calibration (Ma et al., 2000).

Data for calibrating and validating the model of Kapuas River discharge are based on records of the water level in Sanggau in 2006, 2004 and 1999. For the purpose of calibration and validation, these water level data are converted into river discharge by using rating curve equation as follow:

$$Q=125.99(H)^{1.5318} \tag{1}$$

Where:
Q = river discharge (m^3/s)
H = water level (m)

This equation was obtained from Dinas Sumber Daya Air Propinsi Kalimantan Barat or West Kalimantan Water Resources Agency (Lusiana et al., 2008). First, the Hydrological model of Kapuas River is calibrated by comparing to daily observed data in the year 2006. Then, the model is validated by comparing to daily observed data in the year 2004 and 1999, to show that the calibrated model parameter properly work in different years in Kapuas River basin. The model is expected to be better calibrated with those calibration and validation with different years that have contrast climate conditions.

In this study, four model evaluation statistics are used to evaluate the performance of HSPF model output. The first is a coefficient of determination (R^2) which is defined as the squared value of the coefficient of correlation according to Bravais-Pearson. The second is the Nash-Sutcliffe Efficiency (NSE), a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. The third is a deviation of runoff volume (Dv), assessing the relative deviation of the mean value of the simulated data from that the observed data, and the fourth is an index of agreement (d). The index of agreement was proposed by Wilmot (1981) to overcome the insensitivity of NSE and R^2 to differences in the observed and predicted means and variances (Legates and McCabe, 1999). The equation for those four evaluation criteria are shown as below:

$$R^2 = \left(\frac{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2}\sqrt{\left(P_i - \bar{P}\right)^2}} \right)^2 \tag{2}$$

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(O_i - \bar{O}\right)^2} \tag{3}$$

$$\mathrm{Dv}(\%) = \frac{P_{tot} - O_{tot}}{P_{tot}} x100 \tag{4}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}\left(\left|P_i - \bar{O}\right| + \left|O_i - \bar{O}\right|\right)^2} \tag{5}$$

Where O_i and P_i are the observed and simulated flow at each time step of the evaluation period, and are the mean observed $\bar{O}$ and $\bar{P}$ simulated stream flow during the evaluation period. O_{tot} and P_{tot} are the observed and simulated annual river flow. The range of R^2 lies between 0 and 1 which describes how much of the observed dispersion is explained by the prediction. A value of zero means no correlation at all, whereas a value of 1 means that the dispersion of the prediction is equal to that of the observation. NSE ranges between $-\infty$ and 1.0, with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance (Moriasi et al., 2007). Dv can be any value, but smaller absolute values are desired. Positive values mean overestimation and negative values mean underestimation. The range of d is similar to that of R^2 and lies between 0 (no correlation) and 1 (perfect fit).

4. Results and discussions

4.1. Forest degradation and land cover changes

Kapuas River basin covered an area about 82.89 thousands km^2 (56.75%) of West Kalimantan area and 55.3 thousands km^2 (66.7%) of the basin was designated as forest area. However, high rate of forest degradation and deforestation in several decades has decreased the forest coverage in the basin. Figure 3 presents the area of each land cover category in Kapuas River basin in 1996, 2000 and 2006. In 1996, Kapuas River basin was mainly covered by forest (dryland and swamp forest), which occupied more than 51.5% of the basin area. However, only 37% or 30,691.16 km^2 of the basin was covered by primary forests that are primary dryland forest (25,166.8 km^2) and primary swamp forest (5,524.4 km^2). About 44.1% of the basin area was covered by Agricultural land, bushes and shrubs, 2.1% covered by crops plantation, settlements, bare soil, unproductive wetland, and water bodies while 2.2% of the area cannot be classified due to cloud coverage.

In the year 2000 and 2006, although total forest coverage is still dominant in the basin compare to another land cover, it shows the reducing trend since 1996 particularly in primary forest cover. In 2000, following the significant shrinkage of primary forest, the primary dryland forest covered about 22,737.8 km^2 of the basin area while the primary

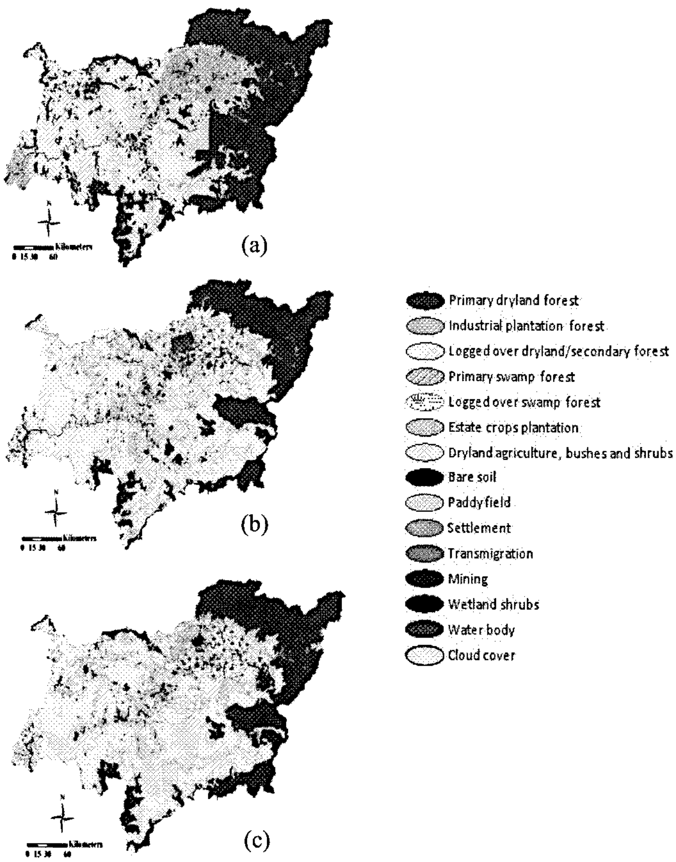

Figure 3: Spatial distribution of Kapuas River basin land covers in 1996 (a), 2000 (b) and 2006 (c).

swamp forest covered about 1,230.6 km². In 2006, even though 49% of the basin was still covered by forest, but more than half of the forest was already degraded (logged-over/secondary forest condition). The primary dryland forest covered about 19,298.9 km² while primary swamp forest covered only 51.4 km² or only 0.06% of the basin area and following these falling trends of primary forest, the degraded forest area increased rapidly.

Figure 4 shows the annual changes of land cover in Kapuas River basin in the period of 1996-2000, 2000-2006, and 1996-2006. Total forest cover reduced by 3.2% from 42,696.77 km² in 1996 to 41,337.08 km² by 2000 and reduced more than 1.7% from 2000 to 2006 and became non forest areas. Not only the total area of the forest had been affected over the years, the quality of forest cover also changed (degraded) in both periods. The primary dryland forest reduced more than 2.400 km² from 25,166.8 km² in 1996 to 22,737.8 km² in 2000, while the primary swamp forest reduced about 4,293.8 km² in that period. On the other hand, in this period logged-over dryland forest and logged-over swamp forest increased by 25.3% and 116.2%, respectively.

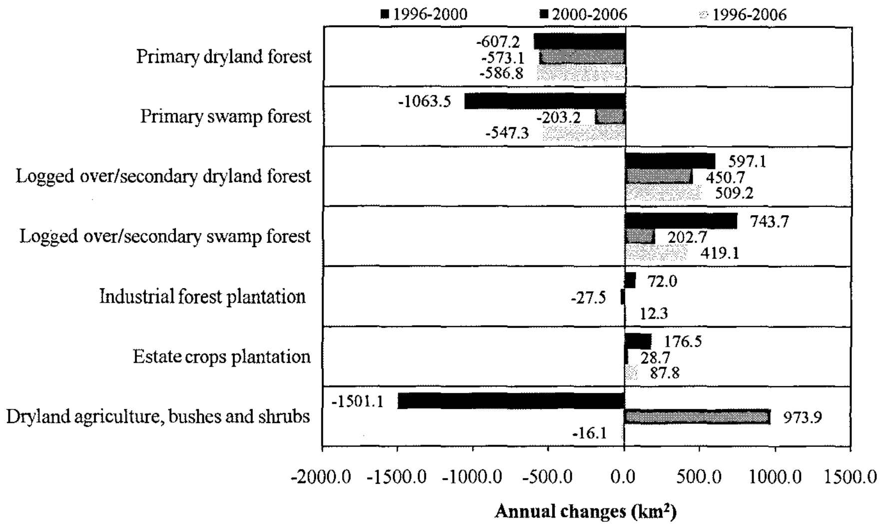

Figure 4: Annual land cover changes in the period of 1996-2000, 2000-2006 and 1996-2006.

Even no significant change of the total amount of forest coverage, the changed of primary forests to secondary/logged-over-forest still continue in the period of 2000 to 2006. The primary dryland forest reduced more than 3,438 km² while the primary swamp forest reduced more than 1,179 km². Moreover, the degradation of primary swamp forest was followed by the increasing of wetland shrubs in the basin about 723.9 km² between 1996 and 2000 and 191.6 km² between 2000 and 2006.

Logging activity in the basin which is mainly managed by natural forest concessions rights (*hak pengusahaan hutan*, or HPH) is one of the factors that contributed to the forest degradation in the basin. Most of the forest areas under the HPH concessions are not well managed and the primary forest tends to decline since its operation was started in 1980's. To maintain forest ecosystem and timber production levels, the Indonesian government launched the industrial plantation forest program (*Hutan Tanaman Industri*, or HTI). However, because of low plantation performance, the HTI effort did not help even in slowing the decline in forest degradation and timber production (Ministry of Forestry, 2006).

Figure 5 presents the condition of HPH and HTI area in Kapuas River basin in 2000 and 2006 land cover condition. Both in 2000 and 2006, most of the HPH and HTI area were covered by bushes, shrubs and agricultural land

and only small parts of it were still covered by primary forests. Bar graphic in Figure 5 shows that between 2000 and 2006 more than 673 km^2 of primary dryland forest and more than 52 km^2 of primary swamp forest degraded. However, these changes were relatively small compared to the changes of primary forests in all production forest area which accounted more than 2,068 km^2 and 324 km^2 of primary dryland forest and primary swamp forest. These indicated that less than 32.3% of primary dryland forest degradation in all production forests was caused by lawful timber extraction (logging) activities or less than 19.5% for all primary dryland forest in the basin, while the rests might be caused by others factors.

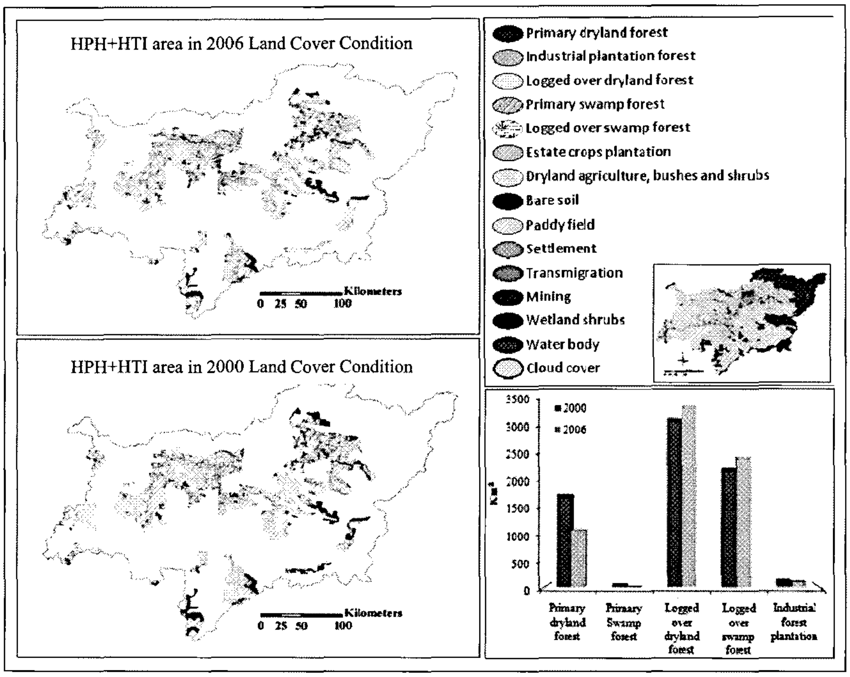

Figure 5: HPH and HTI Land covers condition in Kapuas River basin in 2000 and 2006.

Moreover, Figure 6 shows log production and total number and HPH areas in West Kalimantan which are mainly located in Kapuas River basin. Timber production from natural forest continued to decline from 2.6 million m^3 in 1989 to only 388.32 thousands m^3 in 2004. The figure also shows that after 1998, timber production, number and area of HPH experienced an enormous declining. Up to 2000, more than 82% of log production reduced, while the area and total number of HPH reduced 53.3% and 25.6% respectively. These indicated that the quality of production forest in the basin has declined due to intensive timber extraction activity in the past and the capacity of forest to regenerate was reduced and need longer time due to over exploitation and periodic occurrence of land and forest fire.

Degradation in the quality of natural forest ecosystems which was caused by over exploitation and uncontrolled timber extraction from natural forest and forest conversion has increased the possibility and vulnerability of forest to fire. Siegert et al. (2001) indicated that logged-over-forests were hit harder by fire than undisturbed or partially recovered forest. The logging activity led to a build-up of flammable material on forest floors (logging debris), greater openings in forest canopy and reduced forest density has caused an increased in the frequency of forest and land fires

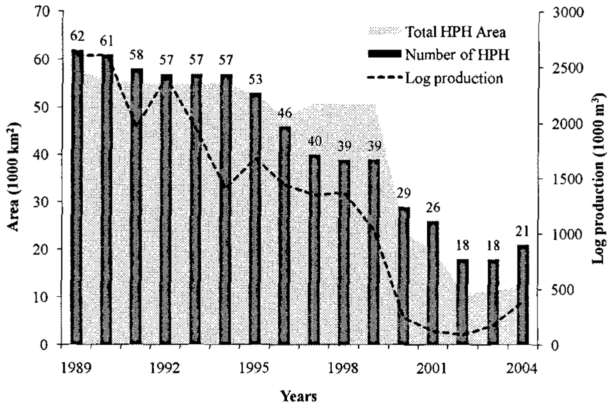

Figure 6: Total number and total area of HPH and timber production from natural forests in West Kalimantan. Source: Ministry of Forestry, 2006

(Ministry of Forestry, 2006). Since severe dry climate condition periodically occurred following the El Niño events, the forest and land fires will periodically occurs as well which in turn hampered of forest regeneration and reforestation in Kapuas River basin. The widespread of land and forest fire which intensely occurs in dry season also contributed to a high rate of forest degradation in West Kalimantan (Kapuas River basin). Forest and land fires were always associated with drought caused by El Niño events. It was recorded that huge forest and land fires in Borneo Island occurred in 1982/1983, 1997/1998, 2002/2003 and 2006 which the strong and moderate El Niño event was taken place. The land and forest fires were much higher in the El Niño years than in years with normal weather conditions (Barber and Schweithelm, 2000; Langner and Siegert, 2008). In 1997-1998 where the strong El Niño events occurred, Indonesia experienced a prolonged and severe forest and land fires. Six months of drought occurred in 1997. Following a short period of rainfall in December 1997, the drought continued through May 1998. During the 1997 ENSO event large fires occurred in Sumatra, West and Central Kalimantan and Papua while in 1998, the greatest fire activity occurred in East Kalimantan (Goldammer and Hoffmann, 2001).

For further analysis, GIS layer with designated forest area and land covers in 2006 were intersected with the hotspot distribution map in 2002, 2003, 2004 and 2005. All results were evaluated concerning the number of detected hotspot. The 2006 land cover data were used because it was free from cloud cover. Therefore, it is important to note that the result might be biased with some underestimation or overestimation of the fire/hotspot affected land covers because some changes of the land covers was occurred before 2006. 63.43% of 2002 hotspot data in Kapuas River basin were located in non forest area while only 36.57% located in designated forest area which is 31.36% located in all production forest area (production forest, limited production forest and convertible production forest), 3.52% located in protection forest and 1.69% located in conservation forest. The similar hotspot distribution pattern also happened in 2003, 2004 and 2005 as can be seen in Figure 7. Furthermore, Figure 8 shows the hotspot distribution for each land cover type in Kapuas River basin between 2002 and 2005. The agricultural land, bushes and shrubs were the most dominant areas affected by fires whereas the logged-over-forest was second dominant. This is similar with previous finding that most of hotspots located in non forest area while production forest which dominantly covered by logged-over-forest was second dominant. Barber and Schweithelm (2000) stated that fires were often started for large scale forest conversion into plantations (forest and estate crops plantation) and land clearance for agriculture since it was the cheapest and fastest way to preparing the land for cultivation. However, since some number of hotspot are also found in the primary forest which was very unusual of fire event because closed canopy forest is high in air humidity and little amount of fuel, it can be noted that strong El Niño which bring severe drought was possible factor of causing natural fires in the primary forests. Nevertheless, it needs further investigation and analysis.

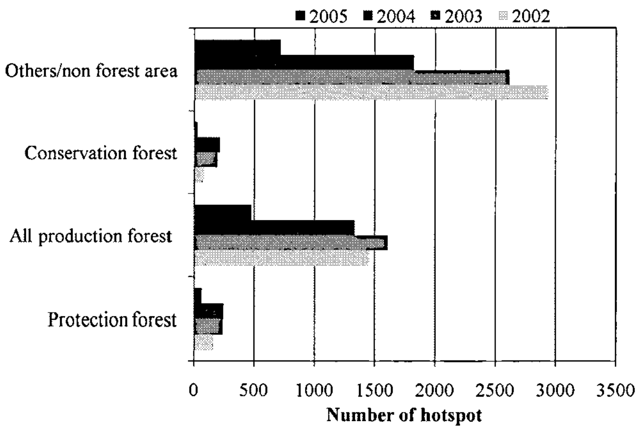

Figure 7: Distribution of hotspot in Kapuas River basin based on designated forest area from 2002 to 2005.

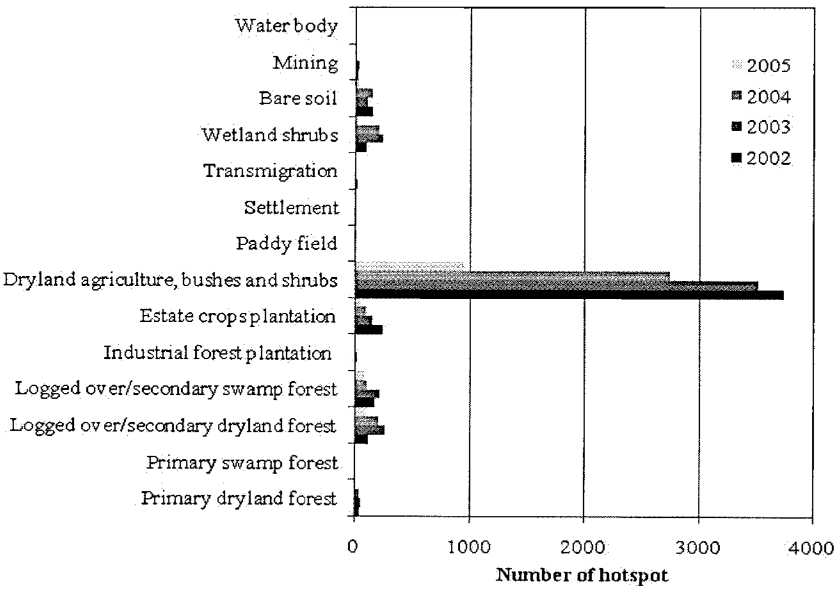

Figure 8: Number of hotspot in each land covers category in Kapuas River basin from 2002 to 2005.

4.2. Hydrological simulation: discharge responses to land covers changes and climate variations in Kapuas River Basin

4.2.1. Model calibration and validation

In calibrating the model, the simulated daily discharge of the basin in Sanggau outlet in 2006 was compared with the observed daily discharge. After calibration process the model was validated based on basin discharge in 1999 and 2004 using all the hydrological parameters which were obtained from calibration process. Figure 9 presents the observed and simulated results of river discharge in Sanggau outlet in 2006, 2004 and 1999 respectively. Even the simulation result behavior was less buffered than the observation discharge especially in the dry period, the simulation results in both calibration and validation years show a fairly good relation with the observation data and are able to reproduce the seasonal trend of river discharge very well.

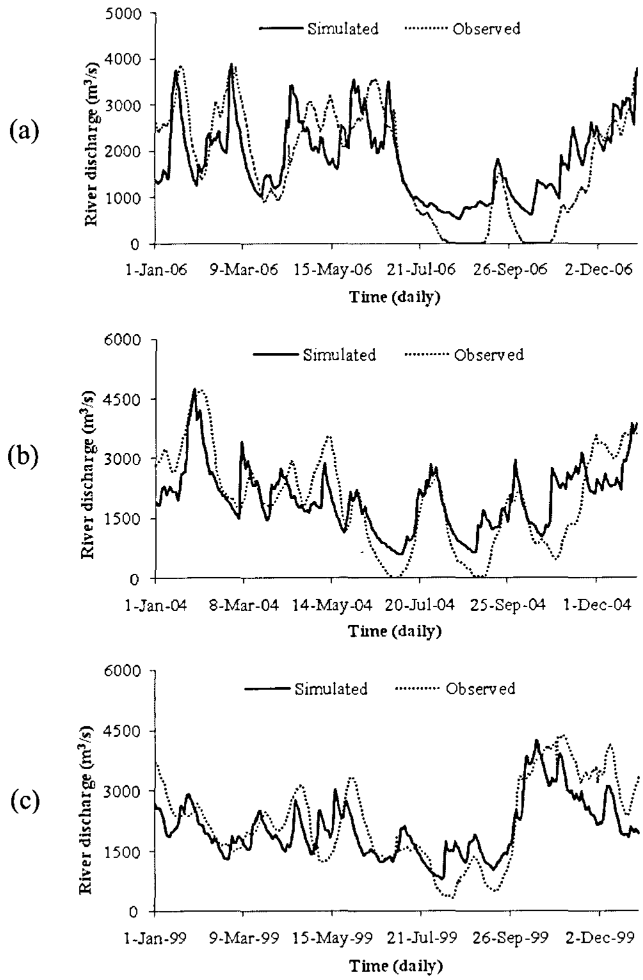

Figure 9: Hydrograph (observed vs. simulated) of Kapuas River in Sanggau outlet in 2006 (a), 2004 (b), and 1999 (c).

Figure 10 presents the scatter plots of observed and simulated daily discharge of Kapuas River in Sanggau outlet. The coefficient of determination (R^2) of 1999, 2004 and 2006 simulation models were 0.66, 0.63 and 0.63, respectively. The United Stated Environmental Protection Agency (US EPA, 2007) stated that for hydrological model, R^2 range between 0.6 and 0.7 shows fair performance, while Santhi et al. (2001) and Van Liew et al. (2003) notify that the R^2 values greater than 0.5 were considered acceptable values. As can be seen the model fairly well reproduces observed daily runoff/flow, even though it noticeably some overestimation.

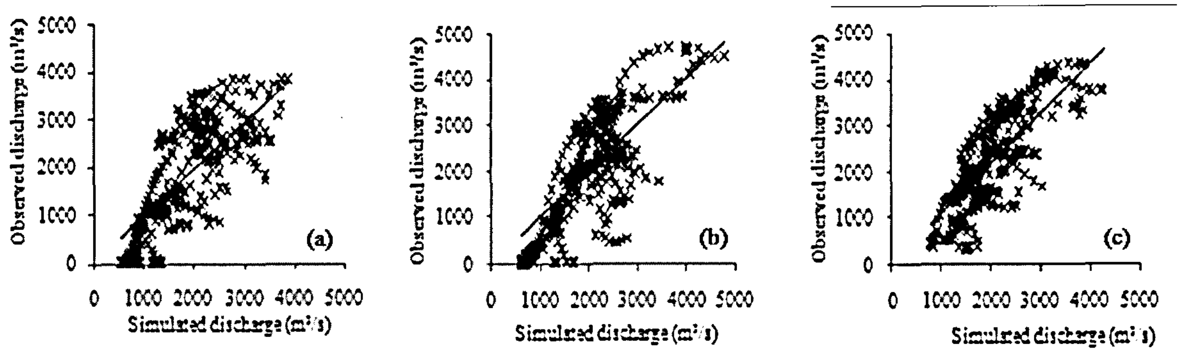

Figure 10: Scatter Plot of observed vs. simulated of Kapuas River in Sanggau outlet in 2006 (a), 2004 (b), and 1999 (c).

The Nash-Sutcliffe Efficiency (NSE) value for all the models was 0.61. Moriasi et al. (2007) clarify that model simulation can be judged as satisfactory if NSE is greater than 0.5. The values of deviation of runoff volume (Dv) and the index of agreement (*d*) also showed good correlations between simulated and observed discharge in all the models. The value of Dv from all the models was smaller than 10 % while the *d* value was higher than 0.7. In general, all the values confirm that the simulation model in calibration and validation period provide a reasonable support for the models ability to describe hydrological situation in Kapuas River basin. This result allowed us to apply the model and evaluate basin discharge fluctuations in response to climate variations and land covers changes.

4.2.2. Sensitivity analysis

The sensitivity analysis was performed to determine the rate of change in model discharge with respect to changes in model parameters values. The sensitivity analysis presented in this study shows selected result of calibration for three specific parameters which are lower zone soil moisture storage (LZSN), index to mean soil infiltration rate (INFILT) and interflow recession coefficient (IRC).

In the first parameter that is LZSN, it shows that higher values of LZSN improved the hydrological model performance. The existing value for this parameter was 15 inches which is the highest recommended values for hydrological simulation.

Different values of INFILT also have change and sensitive to discharge behavior in the basin. Statistically, there were some improvements of model performance resulted from higher INFILT parameters. The same improvement pattern of model performance was also resulted by increasing the IRC parameters. Even IRC was less sensitive than INFILT; higher values of IRC will increase the model performance. The existing model used 0.85 for IRC value because 0.85 is the maximum recommended values and no major improvement if IRC was set higher than 0.85.

4.2.3. Annual and seasonal changes of Kapuas River discharge

Stream discharge of a basin is determined by multiple factors of local climate, land covers, topography, soil and geology. Among them, climate and land covers variation cause most of the observed variability in stream discharge (Hu et al., 2005). Change in climate and land covers alter not only the magnitude and variability of the discharge but also in associated ecosystems and water resources. The effect of climate and land covers changes on Kapuas River basin discharge will be described to understand and disclose the individual and interaction impact of climate and land use on basin discharge.

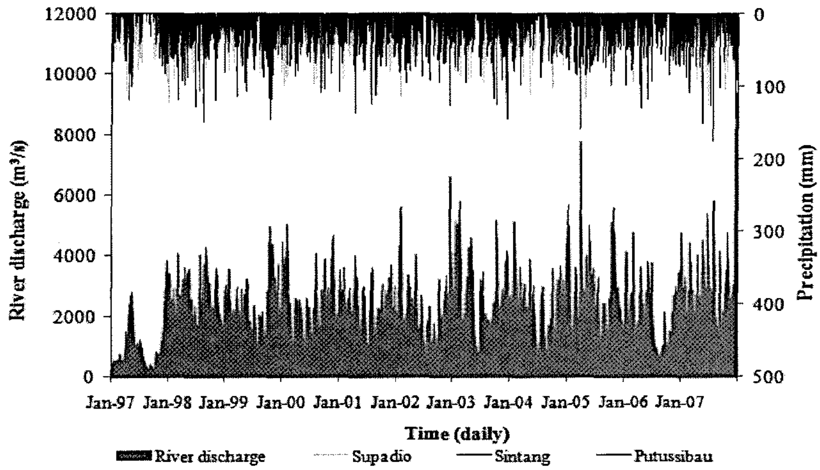

Figure 11: Simulated Kapuas River discharge and daily precipitation in Supadio, Sintang and Putussibau meteorological stations.

Figure 11 presents the rainfall and river discharge pattern in Kapuas River from 1997 to 2007. The rainfall pattern is inverted (with high values on the bottom of the graph), to enable direct visual comparison on the dynamics (fall and rise) of river discharge and rainfall. The precipitation pattern of Kapuas River basin was evenly distributed throughout the year and high precipitation directly followed by peak discharge in the river. The average discharge of Kapuas River in the period of 1997 and 2007 was 2383.9 m^3/s. The basin experienced harsh drought particularly in August 1997 and 2006 with the average discharge of 307.58 m^3/s and 750.12 m^3/s, respectively, while in December 2007 the basin discharge was accounted as highest outflow with the average value of 5,667.48 m^3/s.

To analyze the effect of climate variation into the annual and seasonal change of Kapuas River flow, the year 2006 land use data and climate data from 1997 to 2007 in the three stations within and adjacent to the Kapuas basin (Supadio, Sintang and Putussibau) were used in hydrological model. The climate in that period has been fluctuating between the wet and dry at both annual and seasonal scales. The El Niño and La Niña event also contribute to the climate fluctuations in the basin in that period in different intensities.

Figure 12 shows the relation between El Niño southern oscillations (ENSO) index with the river flow in the Kapuas River basin. ENSO Index is based on the monthly sea surface temperature (SST) anomalies (data are available at ftp://www.coaps.fsu.edu/pub/JMA_SST_Index/) and the Southern Oscillation Index (SOI) data are available at http://www.bom.gov.au/climate/glossary/soi.shtml.

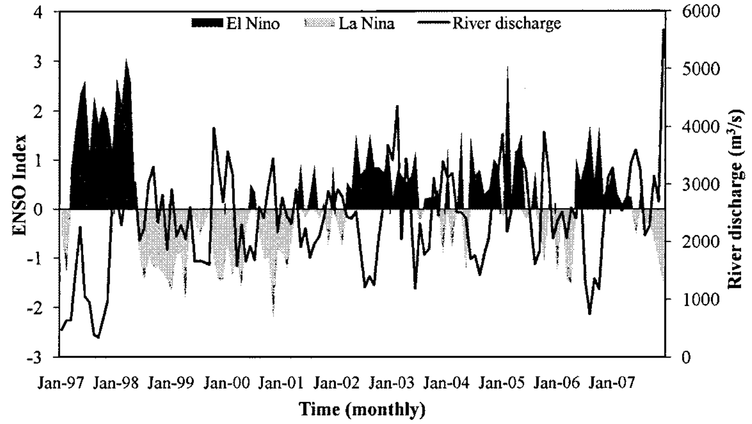

Figure 12: Relations between ENSO Index and average monthly discharge in Kapuas River basin.

In general, there is strong relation between ENSO index and river flow in Kapuas River basin (Figure 12). In the El Niño phase in 1997 (dark-gray color or positive value of ENSO index) only small flow occurred in the basin. These low flows happened in 1997 where the severe drought related to the strong El Niño which reduced rainfall intensity in Indonesia region and corresponded to decreased river flow. The moderate drought in 2002 and 2006 were also followed by small flow in the basin.

Annual changes of Kapuas River discharge between 1997 and 2007 are shown in Figure 13. The dotted line in the figure is the average flow of Kapuas River between 1997 and 2007 which was 2,383.9 m³/s. The average annual flows in 1997, 2002 and 2006 in the basin were under the 1997-2007 average flow while average flow in 1998, 2005 and 2007 were higher than the 1997-2007 average flow. These flow variations were also consistent with the El Niño and La Niña phase occurrence in that period.

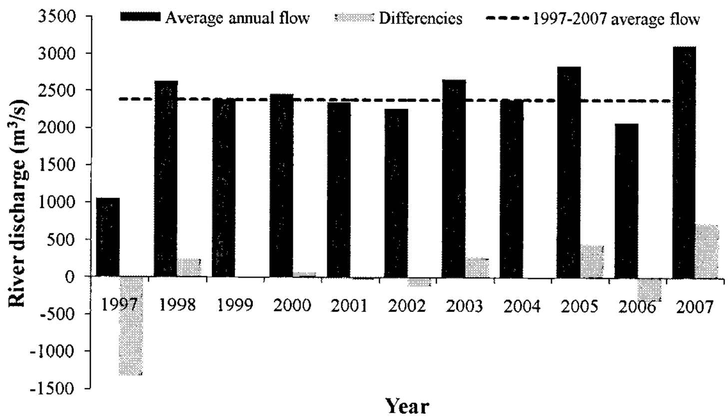

Figure 13: Annual changes of Kapuas River discharge from 1997 to 2007. The dotted line shows the average of 11 years Kapuas River discharge.

4.2.4. Land use change scenarios for Kapuas River discharge

Model scenarios were designed to assess the effect of land cover changes on river discharge in Kapuas River basin. The 2006 land cover was used as control run for the simulation. The control run was used as the reference to which the scenario results will be compared. Some land cover scenario in this experiment represents the 1996 land cover condition, and if; (i) All logged-over-forest area, bare soil, agriculture, brush and shrubs in the basin are changed to primary forest; (ii) All the designated forest area in the basin become primary forest; (iii) All primary forest in the basin changed to agricultural land and shrubs; (iv) All basin area changed to bare soil except residential area (extreme case). Effects of land cover change on river discharge were derived from comparison between model result using different land cover scenarios and control run (2006 land cover). The climate conditions for the model scenario were the same with the control run. The difference between river flow from the model scenarios and those from control run (2006 land cover) describe the effect of specific land covers changes on basin discharge. The results are summarized in Table 1.

Table 1: Land cover changes scenarios and corresponding basin discharge changes.

Land cover change scenarios	Description	% change in basin discharge (1997-2007)			% change in basin discharge in extreme climate events	
		Total	JJA	JND	August 1997	December 2007
1.1996 land cover	Using the 1996 land cover data	-0.8	0.7	-1.7	8.7	-2.6
2.Designated forest	All the designated forest area are changed to primary forest (reforested)	-2.4	2.9	-5.8	30.0	-9.5
All forest	All Logged-over forest area, bare soil, agriculture, brush and shrubs are changed to forest	-4.1	5.3	-9.8	56.5	-15.0
3.No forest	All primary forest changed to agricultural land and shrubs	1.7	-1.4	3.7	-15.8	7.0
4.Bare soil (extreme scenario)	All basin area changed to bare soil except residential	2.9	-2.1	5.4	-38.6	12.5

JJA = June, July and August
JND = January, November and December

The first four scenarios in Table 1 describe the effects on basin discharge from various land cover changes including land cover condition in 1996 whereas the fifth scenario depict the basin discharge change in the extreme scenario (all the basin area except residential area were change to bare soil). Columns 3 to 5 in the table shows percent change of basin discharge corresponded to several land cover scenario relative to 2006 land cover condition in total discharge (1997-2007), total of three driest months (June, July and August) and total of three wettest months (January, November and December).

The first scenario shows basin discharge change that may happen if land cover conditions in the basin were the same with those of 1996 in which more than 51% of the basin covered by forest (with 37% of the basin covered by primary forest). As a result, total basin discharge was decreased about 0.8%. In the second scenario, the basin discharge decreased more than 2.4% if all the designated forest in the basin were reforested and changed to primary forest. More decreased of total basin discharge was resulted from third scenario when returning all the logged-over-forest, bare soil, agriculture, bushes and shrubs land into primary forest. These land cover changes which account for up to 75% of basin area have decreased the total basin discharge up to 4.1%. On the contrary, the fourth scenario shows basin discharge if the rest of primary forest areas (about 24.6% of total basin area) were changed to agricultural land and shrubs. This change caused the increase of total basin discharge about 1.7%. In the last scenario (extreme scenario), total basin discharge increased 2.9% when more than 99% of the basin areas were converted to bare soil. The change in basin discharge from reducing or increasing forest cover in the basin was also found in the previous studies in other regions (e.g., Guo et al., 2008; Hu et al., 2005). The decrease of basin discharge from increasing forest cover might be attributed to the fact that forest land has a higher rate of water loss by large evapotranspiration than agricultural land or bare soil does. Deep roots of forest plants can draw moisture from soils faster than water being transpired by short rooted agricultural plants or bare soil.

Nevertheless, in areas with seasonal rainfall such as West Kalimantan, the distribution of discharge throughout the year is often of greater importance than total annual water yield. For this purpose, the change of basin discharge was analyzed individually in 3 wettest months (June, July and August) and 3 driest months (January, November and December). In the first scenario, the basin discharge increased 0.7% in dry season and decreased 1.7% in wet season compared with basin discharge in 2006 land cover condition. In different magnitude, similar change pattern of basin discharge also happened in scenario two and three which was increased 2.9% and 5.3% in dry season and decreased 5.8% and 9.8% in wet season, respectively. In scenario four, the loss of good forest cover decreased the discharge 1.4% in dry season and increased 3.7% in wet season. Finally, in the extreme scenario basin discharge decreased 2.1% in dry season and increased 5.4% in wet season.

The seasonal change in basin discharge was consistent with the study result in Kunto watershed East Java (Rijsdijk and Bruijnzeel, 1991). They notified that replacing 33% of forest cover by rainfed cropping and settlements increase the streamflow in wet season and decrease it in dry season. Forest decline (less forest coverage) will reduce stream discharge in dry season and raise it in wet season and vice versa. Precipitation is abundant in wet period and temperature is enough to support evapotranspiration at nearly potential rate. As a result, the surface run off decrease substantially in wet season causing large decrease in water yield and stream flow in that period. On the other hand, the increase of water discharge in dry period after returning or change all or parts of basin area into forest cover might be resulted from the groundwater contribution (return flow). The extra amount of surface water which percolated into shallow aquifer after consumption by evapotranspiration becomes the return flow in dry season. Bruijnzeel (2004) revealed that complex interaction of forest root, litters and soil acts as "sponge" which soaks up water during rainy/wet season and releases it evenly during dry periods.

The last two columns in Table 1 show basin discharge in different land cover scenario in August 1997 and December 2007 when the strong El Niño and La Niña were occurred (extreme climate). The absence of forest cover in the basin (scenarios 4 and 5) will increase the possibility of water shortage in dry season by reducing the discharge up to 15.8% and 38.6%, respectively. In contrast, the absence of forest cover will increase the flood risks by increasing the discharge up to 7.0% and 12.5% as shown in scenarios 4 and 5 in December 2007. On the contrary, in scenarios 1, 2 and 3, in different magnitude basin discharge increased in dry season and decreased in wet season as a result of more forest cover the basin. In August 1997, in scenarios 1, 2 and 3 basin discharge increased 8.7%, 30.0% and 56.5%, respectively, while in December 2007 basin discharge decreased 2.6%, 9.5%, and 15.0%, respectively.

When land cover changes occur simultaneously with regional climate events (La Niña and El Niño), the change of basin discharge will be different from their individual effects. To examine the effect of climate and forests/land cover changes simultaneously, three groups of climate were used (wet, average and dry climate) and in each group, monthly discharges from five land cover change scenarios (all forest, designated forest, 1996 land cover, 2006 land cover no forest and bare soil) are shown in Figure 14.

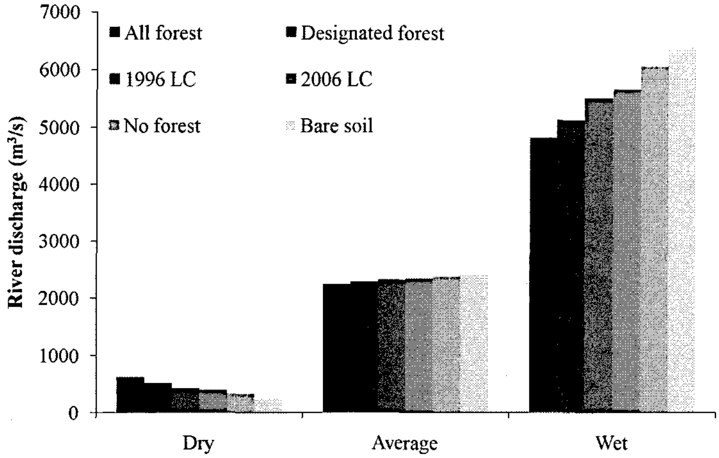

Figure 14: Kapuas River basin average monthly discharge in different land cover conditions in dry climate (August 1997), average climate (monthly average from 1997-2007), and wet climate (December 2007).

There were large differences in basin discharge between the groups while changes of discharge among the scenarios within each group fairly similar to those in Table 1. Further investigations of these different changes depict that the change of discharge from the experiments with only land-cover or climate change was smaller than the effect of simultaneous changes in land-cover and climate. As an example, the basin discharge increased by 114.5% in response to change from the average to a wet climate in all-forest scenario and increased 7.3% when the land cover was changed from all-forest scenario to bare soil scenario in the average climate condition. When both of these climate and land cover changes occurred simultaneously, basin discharge increased by 184.1%, which is greater than 121.8% from the accumulation of the effects from individual changes in climate and land-cover.

Figure 14 also describes that the change of basin discharge which was caused by land cover change depends on the condition/magnitude of the climate events. In normal/average climate, only small change occurs in the basin, while in severe dry or wet climate higher change of basin discharge is taken place.

The most remarkable feature in this figure was the strong change of the basin discharge caused by climate variations compared to those caused by land cover changes. These findings were consistent with previous study result by Lahmer et al. (2001) and Legesse et al. (2003). They concluded that the climatic input data were the most sensitive input and play the dominant role compared with the land cover change in simulated discharge. The effects would be also more significant when there was combination of climate and land cover change.

5. Conclusion and recommendation

There has been a high degradation in primary forest coverage in Kapuas River basin. In total, primary dryland forest reduced by more than 4,460 km^2 (17.9%) while primary swamp forest reduced more than 5,760 km^2 (99%) from 1996 to 2006. Forest degradation in the period of 1996-2000 shows higher rate compare with 2000-2006. Over exploitation of timber from logging activity, periodic fire occurrence, and expansion of estate crops plantation in the basin are the factors that contributed to forest degradation and deforestation.

The applications of Hydrological Simulation (HSPF) in Kapuas River basin show acceptable performance and able to simulate the hydrological behavior particularly on the seasonal trends. Result of sensitivity analysis shows that simulated river discharge is very sensitive to soil infiltration rate (INFILT) and interflow recession coefficient (IRC).

Result of hydrological simulation shows that climate plays a dominant role in changing basin discharge while land cover change which is mainly dominated by change in forest coverage, is secondary. Moreover, it is indicated that the combined effect of forest/land cover change and climate variation is bigger than the sum of its individual change effect. However, even though the annual amount of discharge nearly unchanged, different land cover scenario can cause increase/decrease of discharge in different season. These results suggest that forest/land cover changes can modify drought in dry climate or flood in wet climate. These findings could be important and useful for mitigating the climate change on environment (water resources) by planning proper land use to get desired hydrological effect in the basin.

References

Barber, C.V. and Schweithelm, J. (2000), *Trial by Fires and Forestry Policy in Indonesia's Era of Crisis and Reform.* World Resources Institute (WRI), Forest Frontiers Initiative in collaboration with WWF-Indonesia and Telapak Indonesia Foundation. Washington D.C., ISBN 1-56973-408-9.

Bicknel, B.R., Imhoff, J.C., Kittle, J.L., Jobes, T.H., Donigian Jr. A.S., (2001), *Hydrological Simulation Program Fortran: User's Manual for Version* 12. United States Environmental Protection Agency, National Exposure Research Laboratory, Athens, Ga, EPA/600/R-97/080.

BPS Kalimantan Barat (2008), *Kalimantan Barat Dalam Angka (West Kalimantan in figures) 2008*, Badan Pusat Statistik (BPS) Provinsi Kalimantan Barat. Katalog BPS, 1403.61.

Bruijnzeel, L.A. (2004), Hydrological function of tropical forests: Not seeing the soil for the trees? *Agricultural, Ecosystem and Environment,* 104 (2004), 185-228.

Goldammer, J. G. and Hoffmann, A. A. (2001), Fire Situation in Indonesia, Forest Resources Assessment WP-55: Global forest fire assessment 1990-2000, *Forestry Department-FAO*, IFFN No. 26 - January 2002, 37-45.

Guo, H., Qi Hu and Tong, J. (2008), Annual and seasonal streamflow responses to climate and land-cover changes in the Poyang Lake Basin, China, *Journal of Hydrology* (2008), doi:10.1016/j.jhydrol.2008.03.020.

Hu, Q., Garry, Willson D., Xi Chen and Adnan, A. (2005), Effects of climate and land cover change on stream discharge in the Ozak highland USA, *Environmental Modeling and Assessment,* 10, 9-19.

Lahmer, W., Pfiitzner, B., Becker, A. (2001), Assessment of land use and climate change impacts on the mesoscale, *Phys. Chem. Earth,* (B) 26, 565–575.

Langner, A., Siegert, F. (2008), Spatiotemporal fire occurrence in Borneo over a period of 10 years, *Global Change Biology,* 15, 48-62.

Legates, D.R., and McCabe., G.J. (1999), Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation., *Water Resources Research,* 35(1), 233-241.

Legesse, D., Vallet-Coulomb, C., Gasse, F. (2003), Hydrological response of a catchment to climate and land use changes in tropical Africa: case study south central Ethiopia, *Journal of Hydrology*, 275, 67–85.

Lusiana, B., Widodo, R., Mulyoutami, E., Nugroho, D.A. and van Noordwijk, M. (2008), *Assessing Hydrological Situation of Kapuas Hulu Basin, Kapuas Hulu Regency West Kalimantan*, Working Paper No. 57. Bogor, Indonesia, World Agroforestry Centre, 67p.

Ma, L., Ascough II, J.C., Ahuja, L.R., Shaffer, M.J., Hanson, J.D., and Rojas. K.W., (2000), Root zone water quality model sensitivity analysis using monte carlo simulation. *Trans. ASAE,* 43(4), 883-895.

Ministry of Forestry. (2006), *Indonesia's Forestry Long Term Development Plan 2006-202,* Centre for Forestry Planning and Statistics, Forestry Planning Agency – The Ministry of Forestry of Indonesia, Jakarta.

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D., Veith. T.L., (2007), Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, *American Society of Agricultural and Biological Engineers,*50(3), 885-900.

Nash, J.E. and Sutcliffe. J.V., (1970), River flow forecasting through conceptual models: Part 1, a discussion of principles, *Journal of Hydrology,* 10(3), 282-290.

Rijsdijk, A., Bruijnzeel, L.A. (1991), *Erosion, Sediment Yield and Land Use Patterns In the Upper Konto Watershed, East Java, Indonesia.* Konto River Project Communication, vol. 3. Konto River Project, Malang, Indonesia, 150 p.

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, R., and Hauck. L.M., (2001), Validation of the SWAT model on a large river basin with point and nonpoint sources, *Journal of American Water Resources Association,* 37(5), 1169-1188.

Siegert, F., Ruecker, G., Hinrichs, A., Hoffmann, A.A., (2001), Increased damage from fires in logged forests during droughts caused by El Niño, *Nature*, 414, 437-440.

US EPA. (2007), Lecture #5: *Hydrological Processes, Parameters and Calibration. BASINS 4 Lectures, Data Sets, and Exercises*. United States Environmental Protection Agency. (http://www.epa.gov/waterscience/ftp/basins/training/b4lec05).

Van Liew, M.W., Arnold, J.G. and Garbrecht. J.D., (2003), Hydrologic simulation on agricultural watersheds: choosing between two models, *Trans. ASAE,* 46(6), 1539-1551.

Willmott, C. J. (1981), On the validation of models, *Physical Geography,* 2, 184-194.

Wright, K., Sendeck, K., Rice, R., Thomas, R. (1990), Logging effects on streamflow: storm runoff at caspar creek in northwestern California, *Water Resources Research,* 26 (7), 1657-1667.