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ANALYSIS OF RIVER FLOW REGIME CHANGES RELATED TO WATER AVAILABILITY ON THE KAPUAS RIVER, INDONESIA†

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INTRODUCTION

River flow regime change is strongly influenced by the hydrological characteristics of the river basin. The main characteristics of a river basin are rainfall and land cover types. Rainfall in a river basin generates runoff, which eventually joins the

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†Analyse des changements de régime de flux de la rivière Kapuas (Indonésie) et de l'impact sur la disponibilité en eau.

river. During this movement, the factor of land cover type influences the amount of water that will finally join the river and become available for use. Land cover type is determined by land use type. Activities that change land use types can enhance or reduce the water yield (Asdak, 2001). Global climate change has affected river flow regimes (Arnell and Gosling, 2013), as has land use conversion, and the land cover changes associated with it (Hartcher and Post, 2008).

Land use changes that cause an increase in impervious surfaces reduce infiltration and groundwater recharge and increase surface runoff (Pawitan, 2002). Water table decline directly affects river discharge, which is felt more during the dry season.

The purpose of this study was to: (i) determine the trend of rainfall within a 30-yr period (1981–2013), (ii) determine the land cover changes in the Kapuas River Basin from 1990 to 2012 (last 20 years) and (iii) determine the effect of changes in river flow regime and water availability in the Kapuas River.

The study was conducted on the 1143 km long Kapuas River and its river basin in West Kalimantan. The objective was to investigate the hydrological changes affecting river discharge, rainfall over 30 years (1981–2013) at Supadio Station, Pontianak, West Kalimantan, land use and land cover changes during 1990–2012 in the Kapuas River Basin and river discharge variation from 2002 to 2012.

The Kapuas River Basin is located between coordinates 2° 00′ S–2° 00′ N and 108° 00′ E–114° 30′ E and has an area of approximately 100 000 km^2 (BWSK-I, 2010). The nine sub-basins forming the river basin are: Peniti Besar, Kapuas, Sekh, Bunbun, Gandawalan, Penebangan, Kelelawar, Karimata and Serutu. Of the above, the Kapuas River Basin is the largest and it discharges directly into the sea.

Rainfall analysis was carried out by using the time series 1981–2013 in MS Excel 2007 software. Land use data were culled through interpretation of Landsat imagery TM (thematic mapper) recorded in 1990, 2003 and 2012. Changes in land use and land cover types were obtained by overlaying two land use maps of different years.

RESULTS AND DISCUSSION

Rainfall trend

Hydrological aspects reviewed in this study are rainfall and land cover types. Analysis revealed an increasing trend of rainfall from 1981 to 2013 (Figure 1). Based on these data, the trend of annual rainfall showed an increase of 4.3%. The 30-yr annual and monthly average rainfall amounts are 3140 and 262 mm, respectively.

In dry years, which occurred in 1982, 1991, 1997, 2002 and 2006, the rainfall was below the lower limit, which is less than 2900 mm; whereas in wet years, which occurred in 1987, 1988 and 2007, rainfall was over the upper limit, which is more than 3500 mm. If the rain in coming years is greater, then the trend will continue to increase. But if dry years occur more frequently, then the trend will decrease.

Rainfall over the river basin has been sufficient to meet the water demand for drinking, irrigation and other needs. But, in fact, that does not happen, as rainfall and runoff are concentrated in a few months of the year, causing a very large variation between the maximum and minimum discharge.

During storms, runoff is high due to a higher hydrologic curve number (CN) on account of land use and land cover changes (Suryani and Agus, 2005). A CN is a function of soil type, land use, soil water content prior to a storm rainfall (SCS Engineering Division, 1986), and slope (William, 1995).

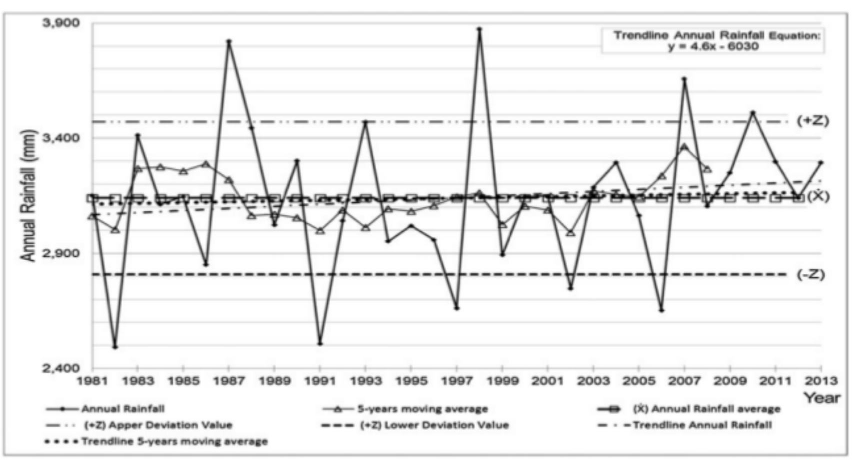

Figure 1. Rainfall pattern (1981–2013) at Supadio, West Kalimantan, Indonesia (Herawati *et al.,* 2013; BMKG Supadio, 2014).

During the dry months, saltwater intrusion extends 50 km upstream in the Kapuas River (Kompas, 2012), so the river cannot meet the water needs of the community. Irrigation is also affected. The area in West Kalimantan Province is dominated by lowland agriculture (62%), thus the availability of quality water from the Kapuas River is indispensable for meeting the irrigation water demand.

Land cover change in the Kapuas River Basin

From the field data throughout the last 20 years the changes in land use in the Kapuas River Basin have been derived. Increasing land use types are swamps, open land and plantations, while decreasing land use types are secondary swamp forest and primary dry forest.

Table I. Land use and cover in the Kapuas River Basin over the years

No.	Land cover	Land cover area							
		1990		2003		2012		Land cover changes[a]	
		ha	%	ha	%	ha	%	ha	%
1	Primary dry forest	2 210 000	22.1	1 980 000	19.8	1 970 000	19.7	(243000)	−2.4
2	Secondary dry forest	1 432 000	14.3	1 585 000	15.9	1 474 000	14.8	42 000	0.4
3	Primary mangrove forests	100	0.0	50	0.0	50	0.0	(50)	−0.0
4	Primary swamp forest	53 000	0.5	28 000	0.3	26 000	0.3	(27 000)	−0.3
5	Forest plants	10 000	0.1	12 000	0.1	12 000	0.1	2 000	0.02
6	Bush	222 000	2.2	213 000	2.1	238 000	2.4	16 000	0.2
7	Plantation	262 000	2.6	224 000	2.2	367 000	3.7	105 000	1.1
8	Settlement	20 000	0.2	19 000	0.2	19 000	0.2	(1 000)	−0.01
9	Open ground/land	50 000	0.5	87 000	0.9	175 000	1.8	125 000	1.3
10	Water bodies	85 000	0.9	103 000	1.0	103 000	1.0	18 000	0.2
11	Secondary mangrove forest	83 000	0.8	81 000	0.8	78 000	0.8	(5 000)	−0.05
12	Secondary swamp forest	1 210 000	12.1	1 144 000	11.4	925 000	9.3	(285000)	−2.8
13	Shrub swamp	132 000	1.3	212 000	2.1	304 000	3.0	172 000	1.7
14	Dry land farming	8 000	0.1	48 000	0.5	51 000	0.5	43 000	0.4
15	Dry land farming mixed	3 980 000	39.8	4 020 000	40.2	4 010 000	40.1	30 000	0.3
16	Rice field	102 000	1.0	102 000	1.0	100 000	1.0	(2 000)	−0.02
17	Fish pond	900	0.0	950	0.0	1 950	0.0	1 050	0.01
18	Airport	100	0.0	100	0.0	100	0.0	–	0.0
19	Resettlement	9 000	0.1	9 000	0.1	9 000	0.1	–	0.0
20	Mining	35 000	0.4	37 000	0.4	44 000	0.4	9 000	0.1
21	Swamp	88 000	0.9	87 000	0.9	88 000	0.9	–	0.0
Total area		9 992 100	100	9 992 100	100	9 992 100	100		

[a]Changes from 1990 to 2012.Source: Landsat image interpretation observed in 1990, 2003 and 2012.

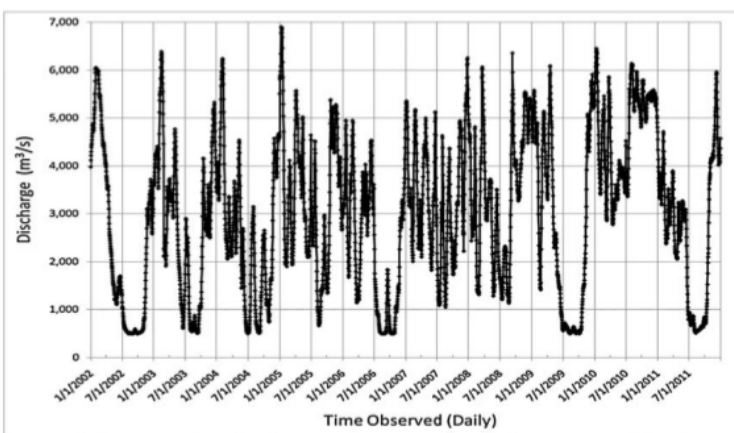

Figure 2. Average daily discharge of the Kapuas River at Sanggau telemetry station (BWSK-I, 2012).

Table II. Flow regime parameter in the Kapuas River, 2002–2011

Year	Q_{max}/Q_{min}	$Q_{80\%}$ ($m^3\ s^{-1}$)
2002	12.1	530
2003	12.6	1 350
2004	12.4	1 000
2005	10.4	2 120
2006	9.9	720
2007	6.0	2 730
2008	5.6	730
2009	12.1	560
2010	2.3	3 860
2011	11.6	750

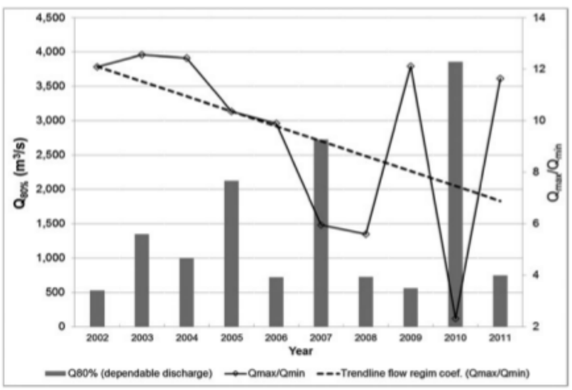

Figure 3. Relation between flow regime coefficient and dependable discharge.

The Landsat image map of 1990–2012 shows that the greatest reductions in land cover types are in secondary swamp forest and primary dry forest. Secondary swamp forest decreased by 2.8% (1 210 000 ha in 1990 to 925 000 ha in 2012) and primary dry forest reduced by 2.4% (2 210 000 ha in 1990 to 1 970 000 ha in 2012). Shrub swamp increased by 1.7% of the total area of the river basin (132 000 ha in 1990 to 304 000 ha in 2012). Open land grew 1.3% (50 000 ha in 1990 to 175 000 ha in 2012). Plantations increased 1.1% (262 000 ha in 1990 to 367 000 ha in 2012). Land use and land cover at Kapuas in 1990, 2003 and 2012 are shown in Table I.

Open land continues to increase widely from year to year in line with population growth. Landsat image analysis results showed that the addition of open land consists mostly of a mix of dry land farming. Although plantations covered most of the additional dry agricultural land, parts of the plantations turned into shrub land. This indicates that agricultural land has not been exploited to the maximum, so much land is not utilized as it should be. This can occur due to the lack of water in the river when it cannot meet the need for irrigation water for crops. From field observations, the rainy season will create a lot of puddles, while in the dry season drought will occur on the land.

Flow regime change against water availability in the Kapuas River

Flow regimes are interpreted here as a form or pattern of open water flow in a river. Precipitation that falls in a river basin

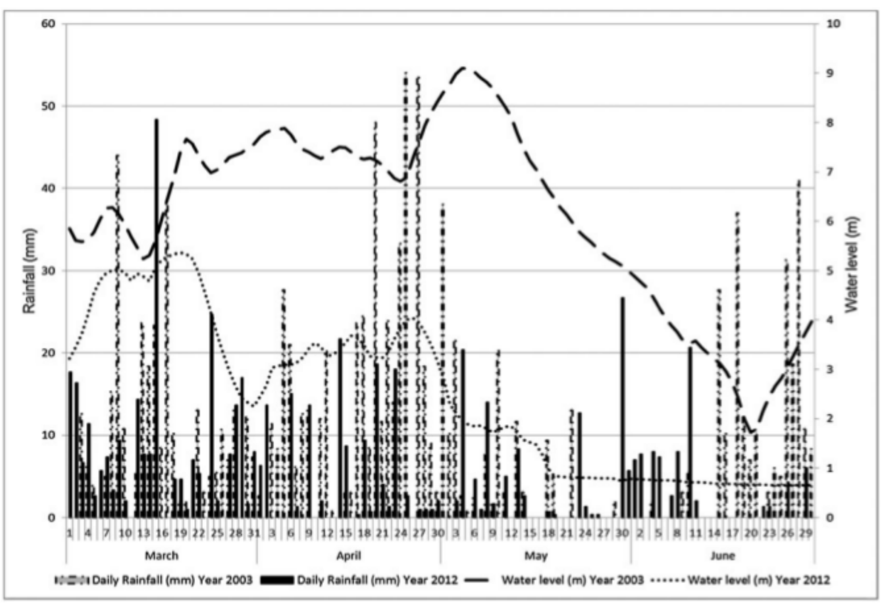

Figure 4. Precipitation and discharge flow in the Kapuas River, 2003 and 2012.

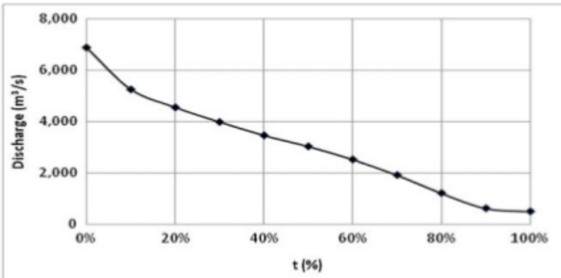

Figure 5. Discharge rating curve in the Kapuas River at Sanggau. [Colour figure can be viewed at wileyonlinelibrary.com]

will partly change to flow in a river. There is thus a relationship between rainfall and discharge rate, which depends on the river basin characteristics (Triatmodjo, 2010). Parameters of maximum and minimum average daily discharge were obtained from daily inflow data of the Kapuas River in 2002 and 2012. Average daily discharge of the Kapuas River at Sanggau telemetry station can be seen in Figure 2. Flow regime analysis can be done by calculating river flow discharge over time based on the following parameters:

- flow regime coefficient is the comparison of maximum (Q_{max}) and minimum flow (Q_{min}) (can be seen in Table II);
- changes in dependable discharge ($Q_{80\%}$) in a river in a certain time frame (can be seen in Table II and Figure 3);
- percentage of discharge above the average discharge to the total discharge was reviewed (*% up*) based on the unit hydrograph analysis and daily rainfall in the long term (10 years).

The average daily discharge of the Kapuas River at Sanggau telemetry station during 10 years' observation is shown in Figure 2. The data show that monthly discharge generally increases during the rainy season, in January–February, and decreases in the dry season, which is in August–September.

From Table II it can be derived that the flow regime coefficient in the Kapuas River is between 2.3 and 12.6, which means that the Kapuas flow regime is unstable. It can also be said that the hydrological characteristics of the Kapuas River are good because the flow regime coefficient is less than 50 (Dirjen. Rehabilitasi Lahan, 2009). However in certain circumstances the Kapuas River flow regime does not follow the rainfall trend. This can be seen in Figure 4.

The availability of water in the river is defined as dependable discharge ($Q_{80\%}$) in a river. Dependable discharge was determined using a mass discharge curve formed by arranging the data flow, from maximum to minimum flow discharge. The composition of the data can be expressed in the form of an image discharge curve, which is shown in Figure 5. Results of the analysis of the discharge measurements known as dependable discharge ($Q_{80\%}$) in the Kapuas River at Sanggau amounted to 1220 $m^3\ s^{-1}$.

Figure 4 shows that from measurements of flow rate in the same season and month in different years (10 years'

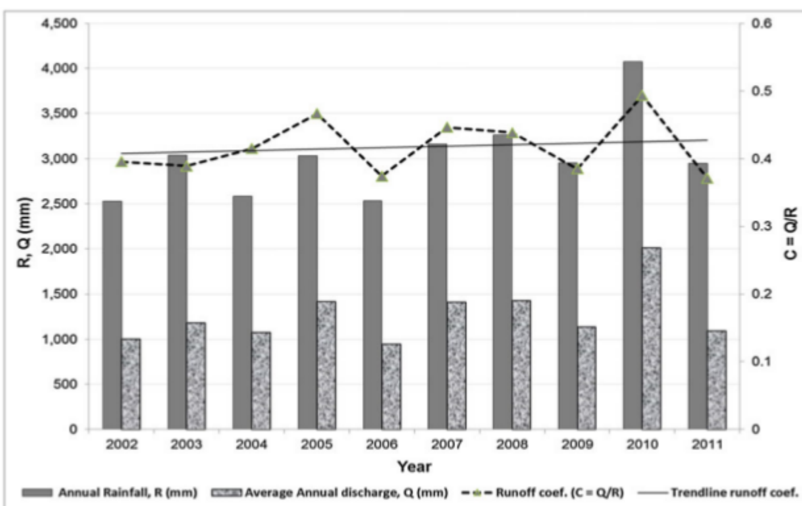

Figure 6. Relation between annual rainfall (*R*), average annual discharge (*Q*) and runoff coefficient (*C*) on the Kapuas River at Sanggau telemetry station, 2002–2011. [Colour figure can be viewed at wileyonlinelibrary.com]

difference), a different discharge change can be derived. In general, the availability of water in the river in 2003 and 2012 followed the trend of rainfall, except that in 2012 despite there being rain the river flow remained constant (this occurred in May and June of 2012).

The water table level declined on 3 May 2003 till 21 June 2013, even though the rain amount occurred to 28 mm on June 15, 2013 but the water level remained declined by 21 June 2013. It proves that the rain which occurs in the Kapuas River Basin is not the determining factor in the Kapuas River water discharge. This can also be caused by land cover type, thereby affecting water runoff to the Kapuas River.

Figure 6 shows the relation between annual rainfall (*R*) and average annual discharge (*Q*) in mm yr^{-1} of the Kapuas River at Sanggau telemetry station (catchment area is 74 100 km^2). It shows that the rainfall trend is not equal to water availability in the river. This is due to the fact that the availability of the Kapuas River water discharge is not solely dependent on the amount of rainfall, but is also influenced by the type of land cover and land use. Land cover and land use affect the value of the runoff coefficient. The runoff coefficient gives the amount of rainwater that enters the river in the form of river water discharge.

CONCLUSIONS AND RECOMMENDATIONS

From the discussion it is concluded that:

- rainfall in the Kapuas River Basin over the last 30 years has increased;
- changes have occurred in land use types during the last 20 years, i.e. land use types that have expanded are shrub swamps (1.7%), open land (1.3%) and plantations (1.1%). Land use types that have decreased are secondary swamp forest, which have decreased by 2.8%, and primary dry forest, which has decreased by about 2.4%;
- the Kapuas River Basin flow regime is unstable. The hydrological characteristics of Kapuas River Basin are good. However in certain circumstances the Kapuas River flow regime does not always follow the rainfall trend, and the water availability trend of the river does not follow the rainfall trend.

Recommendations:

- there is a need to anticipate and manage water resources to the optimum in the Kapuas River, so that the impacts caused by deficiency or excess of water discharge in the river can be managed properly;
- damage control needs of hydrological aspects in the Kapuas River Basin, so that the river basin conditions can be well maintained;
- further studies need to be carried out on the influence of each determinant aspect of hydrology.

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