Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 125 (2015) 185 – 192

Procedia Engineering

www.elsevier.com/locate/procedia

The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

Impact of Climate Change on Streamflow in the Tropical Lowland of Kapuas River, West Borneo, Indonesia

Henny Herawati[a,b,*], Suripin[a], Suharyanto[a]

[a]*Civil Engineering Department in Diponegoro University, Semarang.*
[b]*Civil Engineering Department, Tanjungpura University, Pontianak 78124, Indonesia.*

Abstract

Indonesia is one of the tropical area which its climate is generally experienced of two distinct seasons, rainy season and dry season. However, the beginning and end of each season is not always occurred at the same month on every year. Characteristics of hydrology variables, especially rainfall events, is strongly influenced by local and global climatic conditions. Thus it is important to identify how far the changes of global climate would effect the characteristic of the hydrology variables in a certain watershed. These informations will be valuable to determine the correct measures for the watershed's development and management in the future. Kapuas River, one of rivers in Borneo, Kalimantan-Indonesia, has streamflow which is empirically changed during the last three decades. The changes of hydrological characteristics are analysed statistically based on rainfall data recorded at Supadio Rainfall and Meteorological Station-Pontianak. The monthly rainfall data were available from 1968-2013, while the daily rainfall data were available during 1981-2013. The 1968-2013 data were then used to analyze the trend of annual rainfall, while the 1981-2013 were used to analyze the changes of hydrological characteristics. The results showed that the numbers of average annual rainfall is 3,206 mm, while the average monthly rainfall is 267 mm. During the 45-year period (1968-2013) the annual rainfall tends to decrease, but for the past 30 years it tends to increase. The number of rainy days during the past 30 years tends to increase. Whereas the rainfall intensity on short duration tends to decrease. Even though the availability of streamflow in the river during the past 30 years tends to decrease. It was proven based on observed streamflow in the tributary of Kapuas, Sekayam River. It was found that during 35 years (1978-2012) the availability of streamflow tends to decrease. It is, therefore can be concluded that hydrological characteristics of lowlands at Kapuas River has changed.

Peer-review under responsibility of organizing committee of The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)

* Corresponding author. *E-mail address:*henny_herawati2000@yahoo.com

Peer-review under responsibility of organizing committee of The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5)
doi:10.1016/j.proeng.2015.11.027

Keywords: Climate change; Kapuas Basin; lowland; rainfall intensity; streamflow

1. Introduction

Availability data of a river's streamflow is very important in watershed planning. Generally it is not always available as needed, therefore the streamflow have to be generated from rainfall data. Characteristic of hydrology variables, particularly rainfall is highly influenced by local and global climate [1]. Parameters of climate that influences significantly to rainfall are temperature, humidity and wind [2]; [3]; [4].

The air temperature is predicted to rise due to greenhouse gas emission in the atmosphere until the end of century [5]. This change has impact on rainfall events and climate, as well as to hydrological cycle in the watershed [6]. Increasing temperature and evapotranspiration will impact to runoff volume, so hydrological cycle balance will be interrupted [7]. Therefore, evaluating the impact of climate change is an important topic to be discussed in research on hydrology. Impact of climate change in the watershed had been analysed in several methods, spatial scale, different time period and location, such as watershed in a Denmark river [8]; watershed and soil moisture in Basin Vermillion, Illinois [6]; watershed in Citarum, West Java [9]; watershed in Kampar, Riau [10]. Water-balance in Kapuas showed about 60% of water flows to river and about 40% to interseption and transpiration by vegetation [11].

Indonesia is located in tropical climate zone which is characterised by high rainfall during rainy season and low rainfall during dry season. It causes difficulty to control the water during the rainy season and providing water during dry season [12]. The availability of water in the river is largely determined by the amount of rainfall which transform into streamflow. Located at the equator, is Indonesia's Kapuas River. It is the longest river in Indonesia that located in the Province of West Kalimantan. It is the main source of water for various purposes in West Kalimantan. However, until present, no studies have been conducted to examine the hydrology's charasterictics in the watershed of Kapuas.

Kapuas River is the longest and largest river in Province of West Kalimantan with length of about 1,086 km, across 9 regions and 1 city. Kapuas river is divided into 3 parts of river, upstream, middle-stream and downstream [13]; [14]. Downstream generally is influenced by high and low sea tides generally [15]; [16]. Downstream of Kapuas river is lowland area directly empties into the South Cina Sea.

Changes in streamflow from upstream greatly affect the streamflow in lowland downstream of Kapuas River. In order to anticipate changes in the availability of water caused by global climate change, the purpose of this paper is to find out the impact of global climate changes on charateristics of hydrology in Kapuas Watershed. So that it can be used to take decision and manage the watershed appropriately in the future.

2. Methodology

The study area is Kapuas watershed. Analysis of hydrological characteristics changes made by statistical methods using statistical function in Microsoft Office Excel 2007 software. The methods are the average rainfall amount, standard deviation, rainfall spatial distribution and the trend of rainfall at the Supadio Rainfall and Meteorological Station, Pontianak. The rainfall station is located in the downstream area of the Kapuas River. It is located on 0° 9' 00" North Latitude and 109° 24' 00" East Longitude at 3 meter above sea level. Monthly rainfall data was available from 1968-2013. Meanwhile daily rainfall data available only from 1981-2013. To analyse the changes in characteristic of hydrology, the 33 years of data from 1981-2013 was used in order to obtain rainfall intensity using Mononobe method [17]; [18]; [19] , by analyzing rainfall data per 10 years. Whereas to find out the availability of water in the river, is using the streamflow data in Sekayam River, tributary of Kapuas river, in 1978-2012.

3. Literature Review

Characteristics of hydrology in a watershed is stated in four main parameters, such as precipitation, land cover (to determine surface runoff coefficient) and soil type (to estimate infiltration rate, interflow, and base flow) [6], as well as evapotranspiration [20]. All of these parameters related to each other. Surface runoff occured by observing the correlations between rainfall intensity, evapotranspiration, interception and soil type which consist of soil moisture content and saturated soil moisture content [6].

The amount of evapotranspiration is influenced by temperature, humidity, solar radiation and wind speed. In a particular river, the needed climate data is not always available. Therefore, to analyse the characteristics of hydrology, it can be obtained by reviewing characteristics of rainfall amount in the particular watershed. In hydrology analysis there are some indicators that can be useful [21]; [22]. One of them is the annual runoff, which is defined from a 30-year average annual runoff and also the drought runoff, which is defined from a 10-year return period minimum annual runoff [21].

Two most important meteorological variables which influence climate change are temperature and rainfall. A change in temperature will cause changes in atmospheric variable, and the rainfall spatial-distribution. It means that on a rainy season, a place can have high rainfall intensities and on a dry season the rainfall intensities could be less [9]. Changes in an annual runoff average volume in regional scale, do not always to be linear to changes of global temperature average [21], it means that between amounts of climate changes, the impact response may be complex. Most frequently, the rate of reduction in a runoff will drop as temperature increases, since there is a lower bound on the decrease in precipitation that may occur. In some cases, this suggest that as temperature rise, the effect of increases in precipitation in some parts of the region, will lead to an increased runoff that will consequently offset the effects of reductions in precipitation on reducing runoff in other parts of the region.

Change in climate will have impact to the decreasing of streamflow due to low rainfall intensity. Such as the reduction of streamflow will affect the evapotranspiration during a dry season. For example in Basin Vermillion, Illinois, where the result indicated that reduction of precipitation in summer combined with substantial increase of evaporative demand may lead to the deficit of soil moisture during fall, so that natural vegetation and rain fed crop growth [6]. Changes in rainfall, evapotranspiration and temperature become important factor in environment, agriculture (drainage and flooding) and application in economy (water supply, flooding, engineering and agro-economy) [8].

4. Results

Kapuas River Basin has an area of about 100,284 km^2 or 68.4% from total area of Province of West Borneo or Kalimantan [23]. Streamflow from upstream directly emptied to South China Sea. The analysis results showed that average annual rainfall for 45 years, from 1968-2013 is 3,206 mm. Meanwhile average monthly rainfall annual is 267 mm.

Rainfall in Kapuas Watershed

Figure-1 shows an observational data, taken from 45 years of annual rainy and dry seasons, revealed the decline in the average of annual rainfall trendline. Although the rainfall in 1965 to 1970 is very high, ranging from just over 4,000 mm in 1968, to just under 5,000 mm in 1969, the rainfall level dropped significantly in the next 30 years. Particularly in 1976, which was the driest year, where rainfall is just only 2,483 mm, and 1997 experienced no rain in August or a rainfall level equal to zero. The plummeting of the rainfall level, starts the mid 1970s to 2013, contributes to the decline of the 35-years annual rainfall trendline.

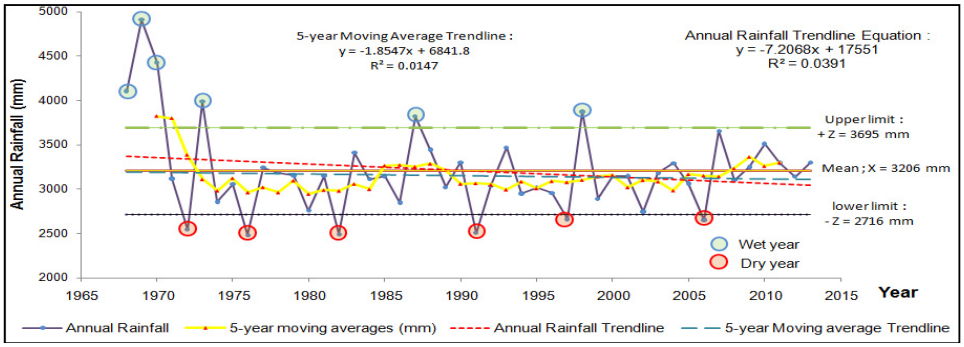

Fig. 1. Annual rainfall and 5-year moving average rainfall at year 1968-2013.

Kapuas river lcated in the equatorial region which is a tropical region, that generally consits of two seasons, rainy season and dry season. However division of the season between rainy season and dry season not always same in every year. It took rainfall data from Supadio station at year 1968-2014, the rainy season was happened on November until January and dry season assumed happened on June until August, shows in Figure 2. The result of analysis monthly annual rainfall showed that monthly rainfall or daily rainfall on dry season was not always dry, even on 1969 when rain happened above average rainfall rainy season, and otherwise on dry season was happened drought just like what happened on 1996. This shows in Figure 2.

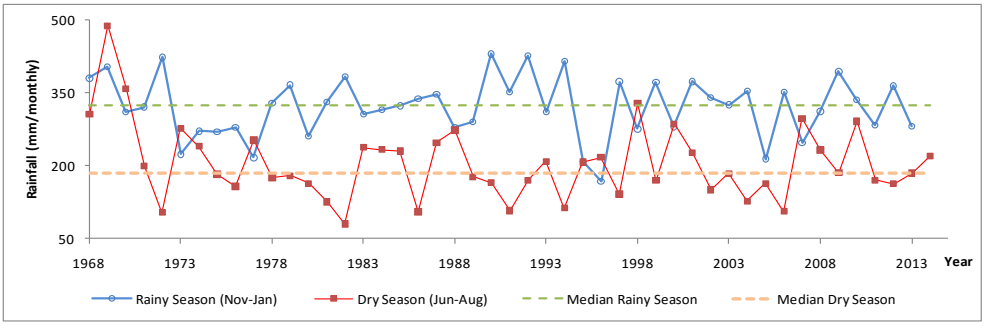

Fig. 2 Lineplot of seasonal mean values per year at Supadio Station, 1968-2013

Kapuas River is located in the equatorial region, which is a tropical region. However the rainy and dry seasons do not start and end in the same month on every year. This resulted in an uneven rainfalls on dry months and on rainy months. As the data taken from the Supadio Station from the years of 1968 to 2014 shows, the rainy season generally began on November and ended on January. Whilst the dry season started from June until August. The record of the monthly annual rainfall amount shows that even on the dry season of 1969, the rainfall level is higher than the one in the rainy season the same year. On the other hand, in 1996 recorded a rainfall that is higher in the dry season compared to one in the rainy season that same year, as shows in Figure 2.

The data from the Supadio Station of Rainfall and Meteorology showed that from 1981 to 2013, the amount of Monthly Rainfall Trendline was increasing, as shows in Figure 3. From monthly rainfall known that rainfall that happened was not always followed certain trend, in generally or based on division of the season.

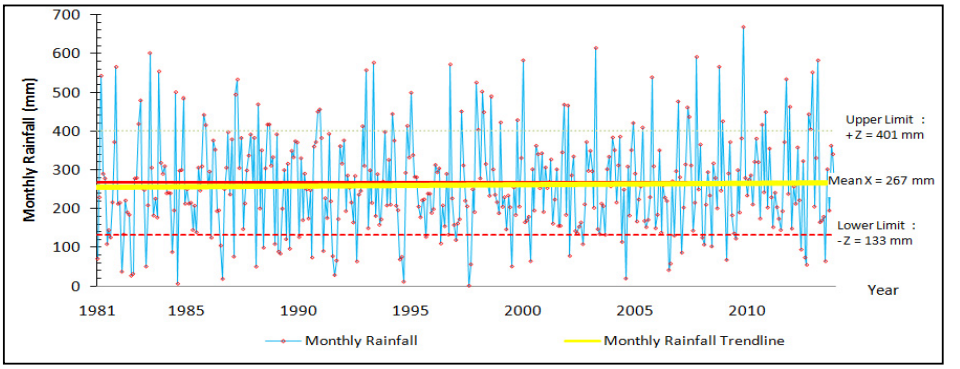

Fig. 3. Monthly rainfall and trendline monthly rainfall 1981-2013.

Climate Change at Kapuas Watershed

Climate change is influenced by the changes of the parameters such as air temperature, humidity and solar radiation [2]; [3]; [4]. Parameter of temperature that was used was the average of daily temperature. The humidity parameter was taken from the average of daily humidity. Parameters of solar radiation is acquired by the percentage ratio of the duration of actual solar radiation to the duration of solar radiation that could have occurred based on the geographic location.

From data observation for 23 years (1991-2013) showed that climate change with increasing of trend at parameters of daily solar radiation, daily temperature average and daily humidity average. As well as evapotranspiration that obtained by calculated with Penman method [24] showed trendline tend to increase.

Number of Rainy Days

The Supadio Station recorded that during 1981 to 2013, the rainy days trendline was increasing, as shows in Figure 4.

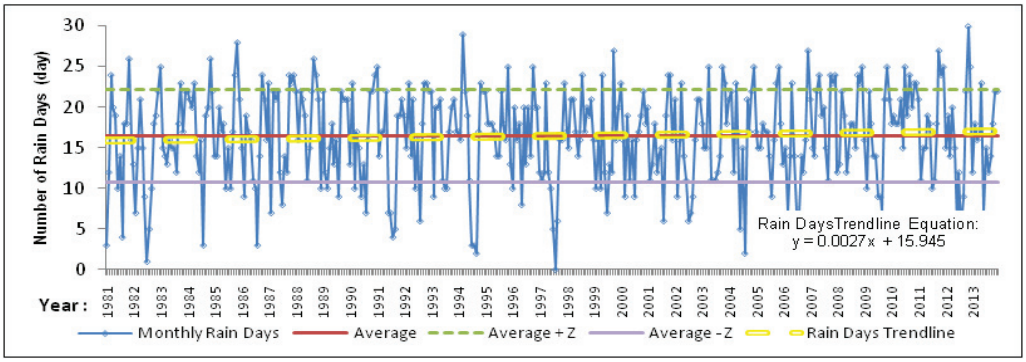

Fig. 4. Trendline in changes numbers of rain days per year at Supadio Station on 1981-2013.

Rainfall intensity is the total of rainfall per unit time [25]. Rainfall intensity can be calculated by Mononobe Method [17]; [18]; [19]. Using the relationship between Intensity-Duration-Frequency (IDF) of rainfall amounts, the intensity with return period more than 10 years, showed a decrease. It can be seen that rainfall intensity from 2003 to 2012 were much lower than the rainfall intensity obtained on 1982-1992 and on 1993-2002, as shows in Figure 5.

Availability of streamflow at Kapuas Sub Watershed

The changes of climate and rainfall influence the availability of streamflow at Kapuas river. One of the tributary of Kapuas river is Sekayam river. Observation station of water level at Sekayam river located at Kembayan, Sekayam Sub District, Sanggau Region, at 110^0 25' 16" East Longitude and 0^0 33' 14" North Latitude. Drainage area of Sekayam river at observation site has 2,290 km^2 area. Streamflow observation was recorded for the period of 1978-2012 [26].

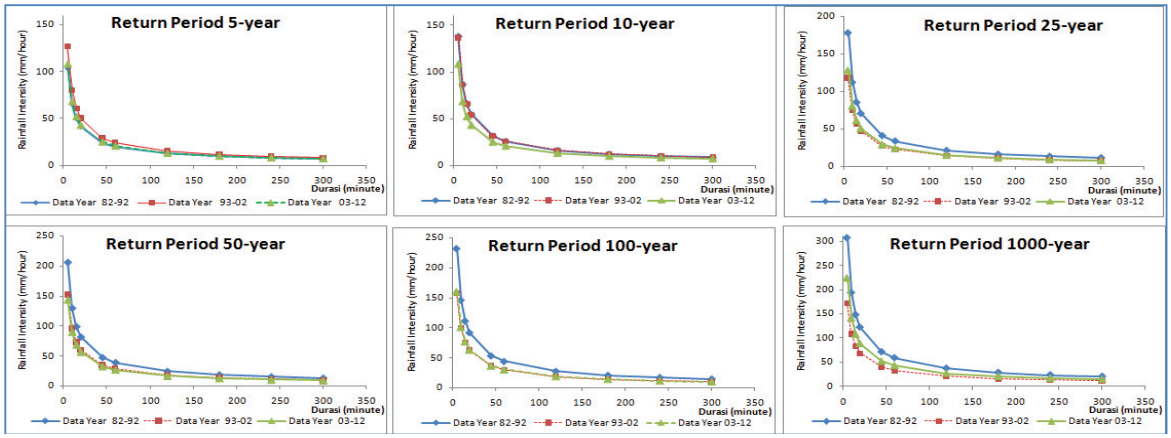

Fig. 5. Rainfall intensity (IDF) per return period at Supadio Station using data during 1982-2012.

Availability of streamflow in Sekayam river, tributary of Kapuas river, for the last 35 years tend to decrease. Availability of streamflow analysis was done for 2 seasons, i.e. dry season and rainy season. Availability of water on

dry season is availability of streamflow on June until August, and availability of water on rainy season is availability of streamflow on November until January. From analysis each season, the availability of water on dry and rainy season tend to decrease. The streamflow analysis for each seasons was divided into three categories, which are maximum streamflow, minimum streamflow and average streamflow. Availability of maximum streamflow showed a decreasing trend for every years. Meanwhile, minimum availability of annual streamflow showed an increasing trend. The result of analysis for every seasons was not show an irregular pattern for the last 35 years. In the same year, the maximum streamflow during a dry season was higher than the maximum of streamflow during that year's rainy season. It shows on Figure 6.

Analyzing the average streamflow, it showed that for the last 35 years the rainfall amount of one year's dry season was recorded to be higher than the average streamflow in the same year's rainy season. This case showed that the rainfall amount in a relatively shorter dry-period, has increase during the last 35 years. It shows on Figure 7.

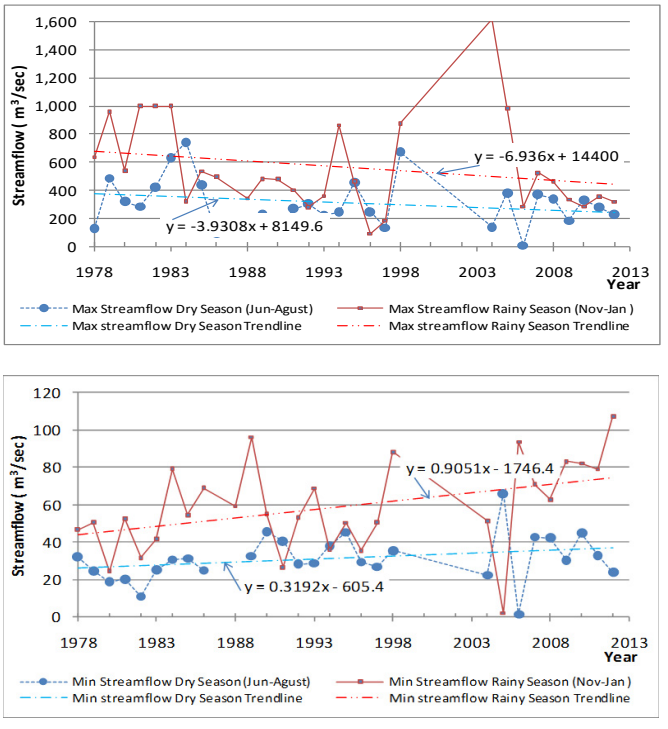

Fig. 6. The status of maximum and minimum streamflow of Sekayam River on 1978-2012 on rainy season and dry season.

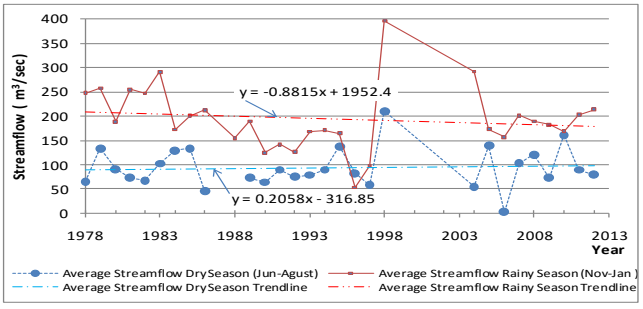

Fig. 7. The status of average streamflow of Sekayam River on 1978-2012 on rainy season and dry season

5. Conclusion

From the description above it can be concluded that there have been changes in the hydrological characteristics of the Kapuas Watershed. The characteristic changes included are, changes to the high rainfall amount, the length of rainy days and change of climate parameters such as temperature, humidity, solar radiation and evapotranspiration. Changes of the annual and monthly rainfall has recorded a declining trendline in the last 45 years. On the other hand, the rainfall amount has been increasing during the last 30 years, although the intensity is decreasing. These characteristic changes affects the availability of streamflow in Kapuas Watershed. The changes in water flow upstream affected the downstream's outline in the area mainly in the lowland downstream. This analysis was performed on a river discharge that occured in a tributary Kapuas River, namely Sekayam River. Based on the analysis of streamflow at Sekayam River showed that on a dry season and a rainy season does not indicate the presence of a regular pattern, and witnessed a different trend for a 35-year period (1978-2012)

This study was recently conducted in several reviews of climate parameters only, such as temperature, humidity and solar radiation that significantly affect evapotranspiration and rainfall. For that we need further advanced analysis of other parameters such as type of land cover, soil type and characteristic of land to determine the extent of surface runoff, infiltration and baseflow, to find out the characteristics' changes of hydrology that were influenced by characteristics of land on Kapuas watershed

Acknowledgements

This research was conducted with financial support to the main author through doctoral dissertation (doctoral grants program) financed by the Directorate General of Higher Education Ministry of Research Technology and Higher Education through a grant letter of Research Assignment Agreement contract number. 046/SP2H/PL/DIT.LITABMAS/II/2015 dated February 5th, 2015. The authors would like to express gratitude to the reviewer who provides valuable comments and suggestions in order to improve the quality of the paper this.

References

[1] Gleick, P. H. (1987). Global Climatic Changes and Regional Hydrology : Impacts and Responses. *The Influence of Climate Change and Climatic Variablity on the Hydrologic Regime and Water Resources* (page. 389-402). Berkeley, California: IAHS.
[2] Winkler, R. D., Winkler, R. D., Moore, Reading, T. E., Spittlehouse, D. L., Carlyle-Moses, D. E., et al. (2010). Hydrologic Process and Watershed Response. *Compendium of Forest Hydrology and Geomorphology in British Columbia* , 133-177.
[3] Wang, Z., Ficklin, D. L., Zhang, Y., & Zang, M. (2012). Impact of Climate Change on Streamflow in the Arid Shiyang River Basin of Northwest China. *Hydrological Processes* , 2733-2744.
[4] Richardson, C., & D.A, W. (1984). *WGEN : A Model for Generating Daily Weather Variables*. Springfield, VA: US Department of Agriculture.
[5] IPCC. (2007). *Climate Change 2007: The Physical Science Basis*. Cambridge, UK: Cambridge University Press.
[6] Tavakoli, M., & De Smedt, F. (2012). Impact of Climate Change on Streamflow and Soil Moisture in the Vermilion Basin, Illinois. *Journal of Hydrologic Engineering* , 1059-1070.
[7] Waggoner, e. a. (1990). *Climate Change and US Water Resources*. Kanada: John Wiley & Sons Inc.
[8] Thodsen, H. (2007). The Influence of Climate Change on Stream Flow in Danish Rivers. *Journal of Hydrology* , 226-238.
[9] WWF-Indonesia, & Universitas Gajah Mada, U. (2007). *Dampak Perubahan Iklim Terhadap Pengelolaan DAS Citarum*. Jakarta: WWF Indonesia.
[10] Kementerian_Kehutanan. (2010). *Tingkat Kerentanan dan Pola Adaptasi Masyarakat terhadap Perubahan Iklim (DAS Kampar) Kuok, Bangkinang Barat, Riau*. Riau: Balai Penelitian Hutan Penghasil Serat.
[11] Lusiana, B., Widodo, R., Mulyoutami, E., Nugroho, D. A., & van Noordwjik, M. (2008). *Kajian Hidrologis DAS Kapuas Hulu, Kapuas Hulu, Kalimantan Barat*. Bogor: World Agroforestry Centre.
[12] Koppen, W. (1990). *Handbuch der Klimatologie*. Jerman.
[13] Rosgen, D. (1996). *Applied River Morphology*. Colorado: Wildland Hydrology.
[14] Leopold, L., Wolman, M., & Miller, J. (1964). *Fluvial Processes in Geomorphology*. San Francisco: W.H. Freeman and Company.
[15] Utomo, A. Z. (1991). *Potensi Perikanan DAS Kapuas Kalimantan Barat. Prosiding TKI Pengelolaan Sungai dan Perairan Umum bagi Perikanan*. Jakarta: Puslitbang Perikanan Jakarta.
[16] Sosial, B. P. (2013). *Pedoman Identifikasi Karakteristik Daerah Aliran Sungai*. Jakarta: Kementerian Kehutanan.
[17] Goo, J. (2001). *A GIS Based Integrated System for Highway Drainage Design*. Seoul: Seoul National University : Department of Agricultural Engineering.
[18] Huff, F. (1967). Time Distribution of Rainfall in Heavy Storms. *Water Resource Research* , 1007-1019.
[19] Yen, B., & Chow, V. (1977). *Feasibility Study on Research of Local Design Storms*. Washington, DC: Department of Transportation, Federal

Highway Administration.
[20] Rahayu, S., Widodo, R., van Noorwidjk, M., Suyadi, I., & Verbist, B. (2009). *Monitoring Air Di Daerah Aliran Sungai*. Bogor: World Agroforestry Centre. Southeast Asia Regional Office.
[21] Arnell, N. W., & Gosling, S. N. (2013). The Impacts of Climate Change on River Flow Regimes at The Global Scale. *Journal of Hydrology* , 351-364.
[22] Doll, P., & Zhang, J. (2010). Impact of Climate Change on Freshwater Ecosystem: A Global-Scale Analysis of Ecological Relevant River Flow Alterations. *Hydrology and Earth System Sciences* , 783-799.
[23] BWSK-I. (2010). *Laporan Pola Wilayah Sungai, Pontianak: Balai Wilayah Sungai Kalimantan I Kalimantan Barat*. Pontianak.
[24] Sahoo, B., Walling, I., Deka, B. C., & Bhatt, B. P. (2012). Standardization of Reference Evapotranspiration Models for a Subhumid Valley Rangeland in The Eastern Himalayas. *Journal of Irrigation and Drainage Engineering* 138, 880-895.
[25] Caine, N. (1980). The Rainfall Intensity: Duration Control of Shallow Landslides and Debris Flows. *Geografiska Annaler. Series A, Physical Geography* , 23-27.
[26] BWSK-I. (2014). *Data Aliran Sungai Sekayam Tahun 1978-2012*. Pontianak: Balai Wilayah Sungai Kalimantan I Kalimantan Barat.