APPLICATION OF CMORPH DATA FOR FOREST/LAND FIRE RISK PREDICTION MODEL IN CENTRAL KALIMANTAN

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Abstract. Central Kalimantan Province is a region with high level of forest/land fire, especially during dry season. Forest/land fire is a dangerous ecosystem destroyer factor, so it needs to be anticipated and prevented as early as possible. CMORPH rainfall data have good potential to overcome the limitations of rainfall data observation. This research is aimed to obtain relationship model between burned acreage and several variables of rainfall condition, as well as to develop risk prediction model of fire occurrence and burned acreage by using rainfall data. This research utilizes information on burned acreage (Ha) and CMORPH rainfall data. The method applied in this research is statistical analysis (finding correlation and regression of two phases), while risk prediction model is generated from the resulting empirical model from relationship of rainfall variables using Monte Carlo simulation based on stochastic spreadsheet. The result of this study shows that precipitation accumulation for two months prior to fire occurrence (CH2Bl) has correlation with burned acreage, and can be estimated by using following formula (if rainfall ≤ 93 mm): Burnt Acreage (Ha) = 5.13 – 21.7 (CH2bl – 93) (R^2 = 67.2%). Forest fire forecasts can be determined by using a precipitation accumulation for two months prior to fire occurrence and Monte Carlo simulation. Efforts to anticipate and address fire risk should be carried out as early as possible, i.e. two months in advance if the probability of fire risk had exceeded the value of 40%.

Keywords: *Forest/Land Fire Risk, CMORPH, Monte Carlo Simulation, Central Kalimantan*

1 INTRODUCTION

Forest fire is the most dangerous forest ecosystem destroyer. It is because forest fire occurs in a short time and spread quickly; yet it can cause great damage. In addition to its impact on forest land and vegetation damage, forest fire can also have negative impact on the environment, including acrid smoke drifted over the island and hazard on human health. Therefore, forest fire need to be anticipated and prevented as early as possible.

Although nearly all forest/ land fire in Indonesia is caused by human activity, whether it is intentional or accidental, climate factor plays an important role. This is related to habitual land clearing and soil preparation for the crop. Severe drought in 1982, 1987, 1991, 1994, 1997/1998, and 2002 due to El Nino climate cycle caused widespread forest fire. Chandler *et al.*, (1983) stated that weather and climate had influence on forest fire through various interconnected ways, i.e. 1) Climate determines the total amount of fuel available, 2) Climate determines the length of time and severity of fire season, 3) Weather controls the moisture content and the ease of forests fuel to burn, and 4) Weather affects the process of forest fire lighting and spreading.

A research conducted by Syaufina et al. (2004) found that rainfall is the most influential climate factor of forest fire in Indonesia, compared to temperature and humidity. Meanwhile, a study carried out by Boer et al (2010) found that forest and land fires in Kalimantan and Riau occur during dry season or when there is no rain for at least 3 days in a row or when daily precipitation is less than 30 mm. Based on previous researches, this study tried to build fire risk prediction model based on CMORPH rainfall data. CMORPH data is useful to overcome limitations on observational data.

Risk is the combination of the likelihood (hazard) which is undesirable (probability of occurrence) and the consequences (vulnerability) (Beer and Ziolkwoski, 1995 and USPCC RARM, 1997 in Boer (2002). Related to forest fire, the risk includes fire lighting and spreading. Fire risk assessment is essential for stakeholder to predict the origin of flame. This is because of wildfire poses a threat to land cover and safety of living beings.

FAO (1986) defined forest fire risk as the chance of a fire starting as determined by the presence and activity of any causative agent. Meanwhile, Chuvieco and Congalton (1989) defined fire risk as the union of two components: fire hazard and fire ignition. The overall risk depends on the fuel and its susceptibility to burn (i.e. hazard), and on the presence of external causes (both anthropogenic and natural) leading to fire ignition. Other sources considered risk as the potential number of ignition sources (Canadian Forest Services, 1997). Chuvieco et al. (2003a, 2003b) mentioned that fire risk is the union of two components, namely fire hazard (the chance of lighting and spread) and fire ignition (as a result or consequence of fire). Fire hazard refers to the prediction of fixed or vary environmental factors (such as fuel, weather, and topography) which determines ignition potential, spread rate, control difficulty, and immediate post burn impact (Merril and Alexander, 1987; Syaufina *et al.*, 2004).

Central Kalimantan has one of the largest tropical peat land forests in the world. Yet due to massive land opening and conversion during 1996 to 1998, and the use of fire to prepare the ground for planting, frequent forest fire occurs especially during dry season. Although the provincial government has tried to lower fire rate, until now Central Kalimantan is still vulnerable to forest/land fire. Therefore, to plan prevention strategies, it requires fire risk prediction model using climate data.

Previous researches utilized data on climate condition and or other element as parameters to analyze fire risk. Anderson et al. (1999) used Soil Dryness Index (SDI) and Normalized Difference Vegetation Index (NDVI) as fire risk determinant and related them with the number of hotspots. Hidayat (1997) and Junaidi (2001) used NDVI only as fire risk indicator, while Canadian Forest Service used Fire Weather Index (FWI) to determine wildfire risk (Dimitrakopoulos, and Bemmerzouk, 1996), which later is adopted by Indonesian National Institute of Aeronautics and Space (LAPAN) to map fire-prone acreage in Sumatra and Kalimantan. Meanwhile, Satriani (2001) mapped out and calculated fire-prone acreage in Kalimantan by using SIG technique. Satriani (2001) implemented overlay and weighting techniques on Keetch-Byram Drought Index (KBDI) (40% by weight), forest type (25% by weight), number of NOAA-AVHRR hotspot (25% by weight), and NDVI (10% by weight) in Kalimantan during 1997–1998 to determine fire insecurity index and calculated the class of fire-prone area (low, medium, or high). Buchholz and Weidemann (2000) compared IKKB to Nesterov Index developed in 1949 by Nesterov on Russia and other European countries to determine the most simple fire risk prediction model on East Kalimantan wildfire in 1997/ 1998. Maki *et al.*, (2004) developed a prediction model to determine fire potential based on moisture content of surrounding vegetation, estimated by Normalized Difference Water Index (NDWI) value which was derived from near infrared (NIR) spectral data and shortwave infrared (SWIR). Adiningsih (2005) developed a regional forest and land fire risk prediction model by scoring variables of monthly rainfall (of 6 class interval), monthly NDVI (of 6 NDVI classes), land cover (of 6 land cover classes), and land types (dry and peat land category) in Sumatra and then analyzed forest and land fire risk under various condition such as climate irregularities.

This research is aimed to obtain relationship model between burned acreage and several rainfall variables. In addition, this research develops a prediction model of forest/land fire potentials and its burned acreage from rainfall data by using Monte Carlo simulation.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The location of this research is Central Kalimantan Province, Indonesia (Figure 2-1). Central Kalimantan lies between 111° East to 116° East and 0° 45´ North, and 3° 30´ South. This province is where the most frequent forest fires occur, especially during dry season.

Data used in this research was Palangkaraya daily CMORPH rainfall data from early 2003 until July 2012. This data was retrieved from http://cpc.ncep.noaa.gov.

Other data used were those of forest/ land forest fire in Central Kalimantan (date, location, and burned acreage) obtained from field survey in 2009 and fire suppression data from Natural Resources Conservation Bureau (Balai Konservasi Sumber Daya Alam/BKSDA), Ministry of Forestry, Central Kalimantan Province in 2011.

Instruments used in this research were computer with Arc-View and Crystal Ball which could be operated in Microsoft Excel and Minitab 14 Statistical Software programs.

2.2 Methods

This analysis was conducted through several stages, as follows:

Stage 1: Download CMORPH data of rainfall in Indonesia. The raw data then was converted into numerical information in order to be readable. Then, geometric correction process was performed on the data to make more precise latitude and longitude coordinates. After that, to acquire rainfall data that covered all Indonesian archipelago, cropping process was carried out. CMORPH data with 0.25o x 0.25o latitude/longitude grid resolution; then was resized into 2.5 x 2.5 km per grid. Afterward, the data was converted into .txt format so that it could be read and processed with Microsoft Excel and Arc View software.

Stage 2: On this stage, rainfall data was extracted from all hotspot to determine average value of CMORPH rainfall data with domain of 3 x 3 and hotspot as grid center. Hotspots which located within 3 x 3 domains or close were grouped into average precipitation value of the same domain.

Stage 3: Based on date forest fire, then the accumulation of precipitation 1 (one), 2 (two), and 3 (three) months before wildfire were decided (i.e. CH1bl, CH2bl, and CH3bl). The number of days without rain during 1, 2, and 3 months before fire lighting were also determined (as HTH1bl, HTH2bl, and HTH3bl). Then, CH1bl, CH2bl, CH3bl, HTH1bl, HTH2bl, and HTH3bl variables were used as the fire risk index (Indeks Risiko Kebakaran/IRK) variables.

Stage 4: Perform statistical analysis on the data to attain relationship model between fire incidence (burned acreage) and all IRK variables. To make it concise, steps in determining IRK as well as relationship model of burned acreage and IRK, from Stage 1 to 4 were presented in Figure 2-2 flowchart.

Stage 5: Further analysis was conducted based on empirical model retrieved in Stage 4 with the best IRK variable to attain fire risk prediction model. Fire prediction model was acquired using Monte Carlo simulation on stochastic spreadsheet. Monte Carlo simulation or probability simulation is a technique to explore sensitivity of a complex system with various parameters based on statistics limitations. Simulation results were analyzed to determine characteristics of the system (Mathwork,-) in order to understand risk or uncertainty of other forecast models (Riskamp,-), or it was used in optimization models, numerical integration, and evoking examples of an opportunity distribution. Monte Carlo simulation used repeated sampling to define properties of certain phenomenon or behavior (Sawilowsky, 2003). Monte Carlo method is also used in ensemble models as the basis of modern weather forecasting methods, to interpret a behavior and to compare experimental results with theory used. In this research, Monte Carlo simulation was performed by using Crystal Ball application on Microsoft Excel.

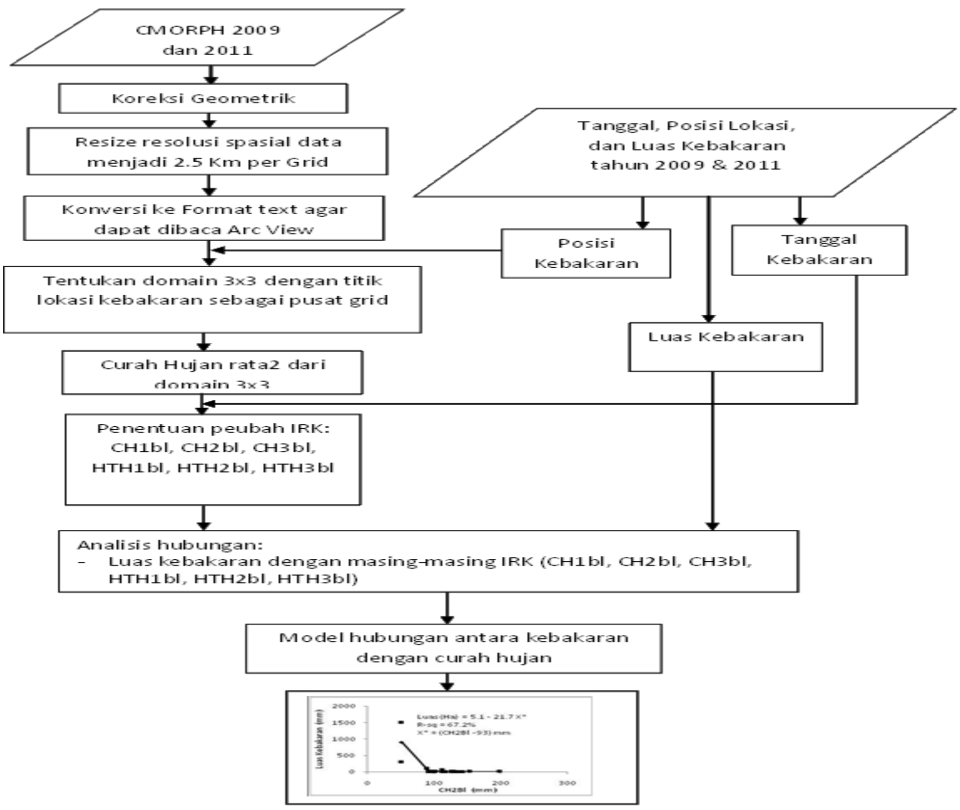


Figure 2-2: Process of Retrieving Relationship Model between Climate and Fire Incidence

3 RESULTS AND DISCUSSION

This research utilizes CMORPH data. CMORPH is a method that produces global precipitation estimates with high spatial and temporal resolution that combines the result of precipitation estimation data from passive microwave data with clouds movement at a height of 4 m above the ground which is extracted from 10.7 µm infrared canal of geostationary satellite (Decision Assistance Branch Meteorological Development Laboratory National Weather Service, 2008). Merger of both data produces an output in the form of: (1) 30 minutes CMORPH with resolution of 0,0727° latitude/longitude above the Equator and includes 60oN – 60oS; (2) 3 hours CMORPH with resolution of 0,25o latitude/longitude and covers global scale; and (3) daily CMORPH with resolution of 0,25o latitude/longitude that covers global scale (Joyce *et al.*, 2004). According to Janowiak (2007, in Oktavariani, 2008), Tropical Rainfall Measuring Mission (TRMM) TRMM Microwave Image (TMI) data which is used to estimate CMORPH precipitation spread has a better ability to predict precipitation due to its low margin of error. With its ability to fill in 2 - 3 months of missing data, CMORPH precipitation estimation model is good enough. Correlation value between observation and its estimates ranges from 0.45 – 0.60 (Oktavariani, 2008).

Analysis on the relationship between fire occurrence and climate condition is performed based on 2009 and 2011 wildfire data. The 2009 data was derived from some hotspot locations surveyed using GPS. Because several hotspot locations were mapped near one another, thus they were grouped into 4 clusters, namely Kalteng 1, Kalteng 2, Kalteng 3, and Kalteng 4. BKSDA Palangkaraya notes that there were 26 forest fires in 2011.

Climatic conditions which served as the determining variables of fire risk index (IRK) to be analyzed and associated with forest fire are: accumulation of 1 month rainfall (CH1bl), accumulation of 2 months rainfall (CH2bl), and accumulation of 3 months rainfall (CH3bl) data prior to forest fire, a month without rain (HTH1bl), 2 months without rain (HTH2bl), and 3 months without rain (HTH3bl) before fire lighting. The use of days without rainfall for 1 – 3 months period variable is intended to generate the best IRK model so that this analysis can be used as fire prediction parameter of 1 to 3 months in advance. Thus, the rainfall forecast that is issued by BMKG can be used as an early warning and burned acreage prediction.

Correlation between burned acreage and respective IRK variables (Table 3-1) shows that there is a negative correlation between burned acreage and accumulation of 1 month rainfall (CH1bl), 2 months rainfall (CH2bl), 3 months rainfall (CH3bl) before the fire. This shows that increase of 1, 2, and 3 months rainfall accumulation before wildfire may decrease the burned acreage. The highest correlation is derived from generating the relation between the burned acreage and accumulation of two months rainfall prior to fire occurrence ($r = -0.5$) with significance level of 95% ($\alpha = 0.05$). Meanwhile, correlation between burned acreage and the highest number of day without rain is obtained from the number of day without rain two months prior to fire (HTH2bl) of 0.41, with significance level of 95%.

Relationship model between burned acreage with each IRK variable is derived from scatter diagram pattern. Moreover, based on existing pattern, regression of two phases is analyzed. Further analysis shows that there is a correlation between burned acreage and accumulation of 2 month rainfall prior to fire, with diversity degree (R2) of 67.2% (Figure 3-1). Meanwhile, other models do not have good correlation result.

Refer to Figure 3-1b and c, if the accumulation of 2 month rainfall is less than 93 mm, then the burned acreage will rise sharply. On the contrary, when accumulated precipitation exceeds 93 mm in the last two months, then the burned acreage will decrease or fire is predicted to not occur. Meanwhile, the number of day without rain, both 2 and 3 month prior to wildfire has insignificant effect on forest fire, of about 20.6% and 15.3% in a row. If the total days without rain exceed 45 days within 2 month prior to forest fire or exceed 66 days within 3 month prior to fire, then the burned acreage may increase (Figure 3-1e and f).

These results show that precipitation factor, especially those during the last two months, greatly affect the chance of forest/land fire spreading. Similarly, a research conducted by Syaufina et al. (2004) proves that from several climatic factors tested in correlation with peat fires in Simpan Sungai Karang Forest in Tanjong Karang, Selangor, Malaysia only precipitation factor shows relatively good relation. Precipitation factor does affect the moisture content which supply fuel to organic life at peat lands. Land cover which often experience fire in Palangkaraya is peat land, since precipitation influences moisture content. Additionally, Ceccato et al. (2007) also finds that precipitation anomaly is a determining factor of forest fire.

Analysis on the relation between burned acreage and IRK variables finds that the best IRK variable to be used as fire risk prediction model is accumulation of 2 month rainfall prior to fire (CH2bl). Thus, fire risk prediction model can be developed using the following equation: Width (Ha) = 5.1 - 21.7 X* (R^2 = 67.2%) with X* = (CH2bl - 93) mm. Furthermore, processes and stages taken in compiling this prediction model to anticipate fire risk is presented in Figure 3-2.

Analysis on the burned acreage is performed by utilizing precipitation data. Assumption of this approach is based on the fact that decrease in rainfall will make the water level to drop, thus the forest becomes more susceptible to flame. These conditions will trigger people's tendency to burn forest for land clearing, increasing forest fire risk.

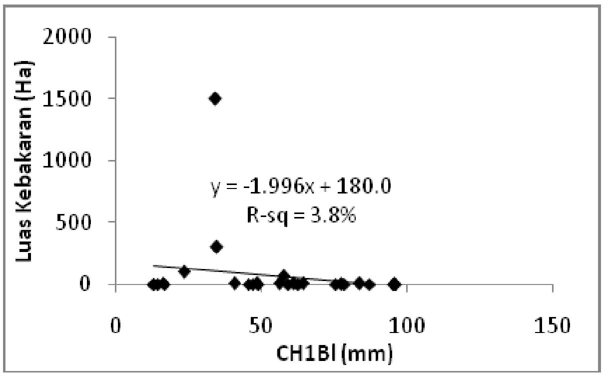
CMORPH precipitation data used in arranging fire risk prediction model is wild forest fire data in 2003 - 2012. Furthermore, based on the rainfall data, normal precipitation distribution is determined; average value and diversity of rainfall is calculated as well as. Bi-monthly precipitation is also calculated to determine two months rainfall pattern and lighting opportunity of less than 93 mm rainfall. If bi-monthly rainfall is below normal or lower than 93 mm, then it is predicted that fire risk for the next two months will be high. By integrating the empirical model with Monte Carlo simulation through stochastic spreadsheet, fire risk occurrence for the next two months can be predicted.

Furthermore, to predict the chance of rain requires updated information on precipitation data for the last two months. Bi-monthly rainfall information has certain margin of error. This error value determines level of fire forecast certainty. The smaller the margin of error, the greater level of fire forecast certainty will be. When there is not any information on margin of error, then the highest error value of bi-monthly rainfall can be predicted by comparing coefficient variance (CV) and rainfall average. Thus, the burned acreage can be estimated based on rain condition, i.e. bi-monthly rainfall prior to forest fire.

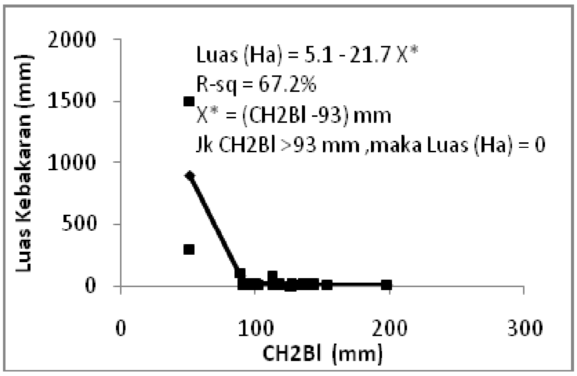
Table 3-1: Correlation between Burned Acreage (Ha) with Each IRK

	CH1bl	CH2bl	CH3bl	HTH1bl	HTH2bl	HTH3bl
Width (Ha)	-0.20	-0.50*	-0.40*	0.12	0.41*	0.37

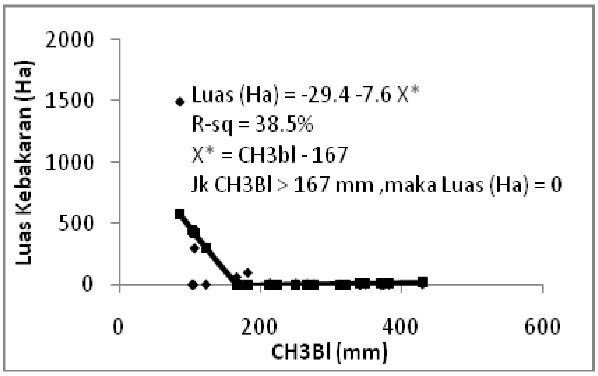
Description: * significance level of 95% (α = 0.05)



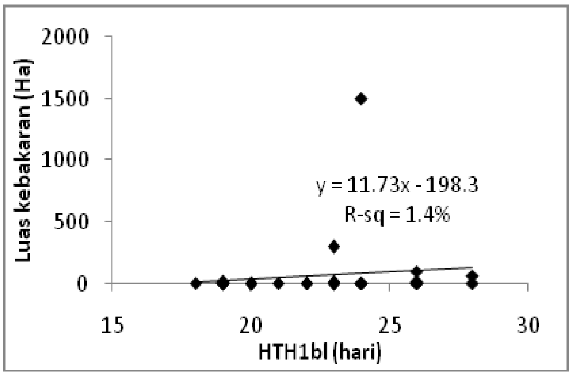
a. Burned acreage VS accumulation of 1 month rainfall prior to forest fire



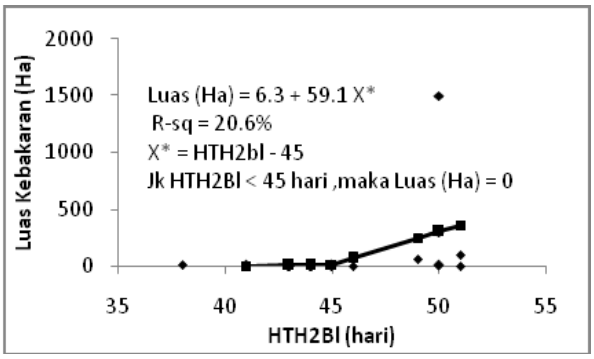
b. Burned acreage VS accumulation of 2 months rainfall prior to forest fire



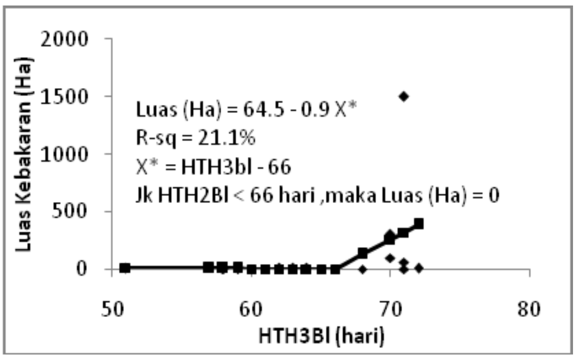
c. Burned acreage VS accumulation of 3 months rainfall prior to forest fire



d. Burned acreage VS total clear days without rain in 1 month prior to forest fire



e. Burned acreage VS total clear days without rain in 2 months prior to forest fire



f. Burned acreage VS total clear days without rain in 3 months prior to forest fire

Figure 3-1: The relation between Burned Acreage and Climate Condition Parameter

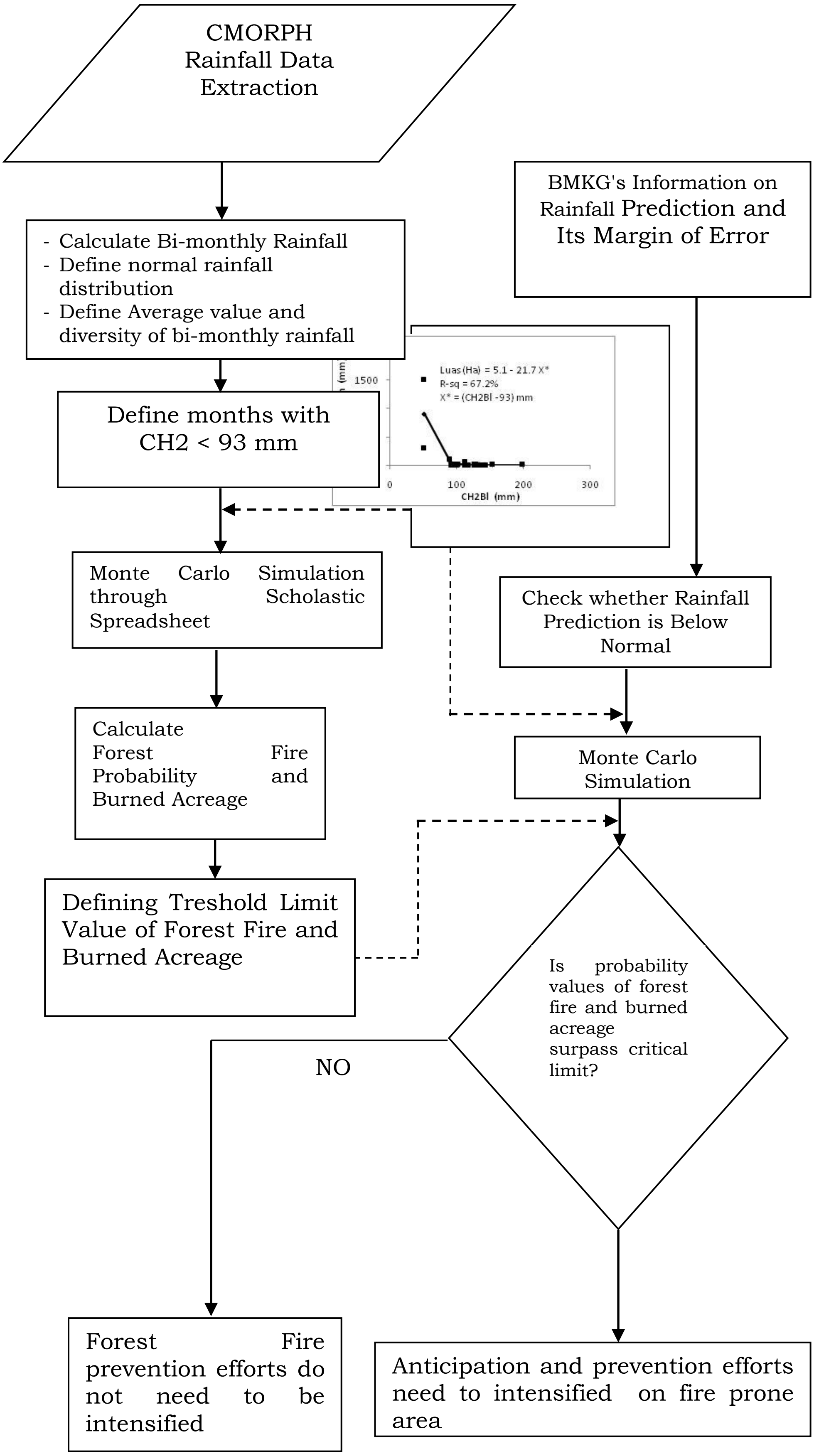


Figure 3-2: The Process of Compiling Risk Prediction Model to Anticipate and Prevent Forest Fire based on Rainfall Data (Curah Hujan/CH)

Result of this analysis shows that when bi-monthly rainfall is lower than 93 mm, then the risk of a fire to occur will increase and so will the burned acreage. Based on bi-monthly rainfall pattern, months with the highest chance of fire occurrence due to lower than 93 mm rainfall are July and September (Figure 3-3). If monthly rainfall data issued in June or July is lower than 93 mm, then it is expected that fire risk during September or October will be high. By using Monte Carlo simulation, wildfire is likely to occur in September or October when rainfall on July-August or September-August is recorded normal, ranging from 15% to 20% (Figure 3-4). Since wildfire must be avoided, then related shareholder must prevent fire lighting by considering data of least 20% opportunity of forest fire. In other words, when weather forecast provider (BMKG) issues high chance of fire occurrence, i.e. above 20%, then anticipation efforts should be taken to prevent forest/land fire.

To predict wildfire occurrence in September and October during the period of 2003 to 2011, then Monte Carlo simulation is carried out based on bi-monthly rainfall data on July-August and August-September of each year. Therefore, to utilize this risk prediction model, in addition to provide forecast information on the character of seasonal rainfall (Below Normal, Normal or Above Normal), BMKG should also issue margin of error of its prediction. In Indonesian region with strong ENSO influence, the level of forecasts certainty will be high (small margin of error), and therefore fire prediction certainty will be high.

For the purpose of yearly wildfire simulation in September and October according to July-August and August-September rainfall data, it is predicted that bi-monthly margin of error is based on equality relationship between diversity coefficient (CV) and rainfall average (Figure 3-5). This analysis shows that 2006, 2009 and 2011 are years which forest fire opportunity surpasses the critical value of 20% (Figure 3-6).

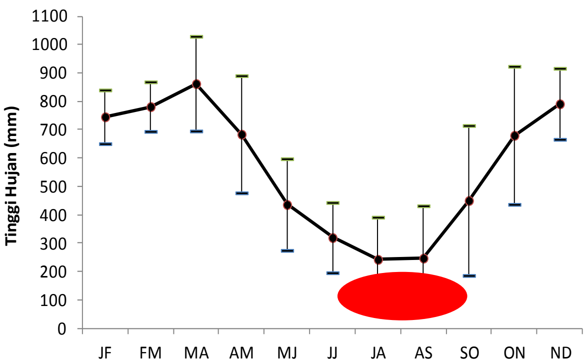


Figure 3-3: Bi-monthly rainfall pattern in Palangkaraya

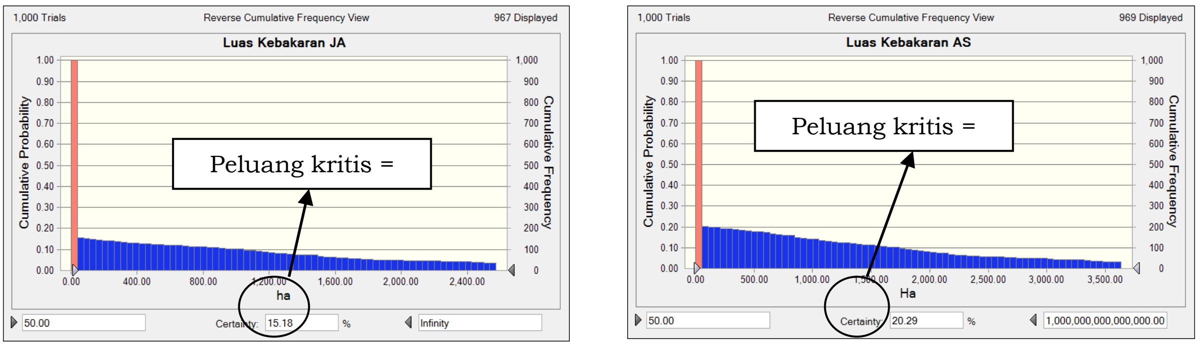


Figure 3-4: Fire cumulative opportunity (width > 50 ha) in September (left) and October (right) in Palangkaraya when bi-monthly rainfall character is normal

Median of burned acreage value for September 2006, 2009 and 2011 are 1.380, 1.539 and 1.520 hectares respectively, and while for October are 980, 80 and 0 hectare subsequently. This analysis indicates that the chance of fire occurrence in October 2009 is less than 20% and if the fire breaks out, then the widespread will be less than 100 hectares.

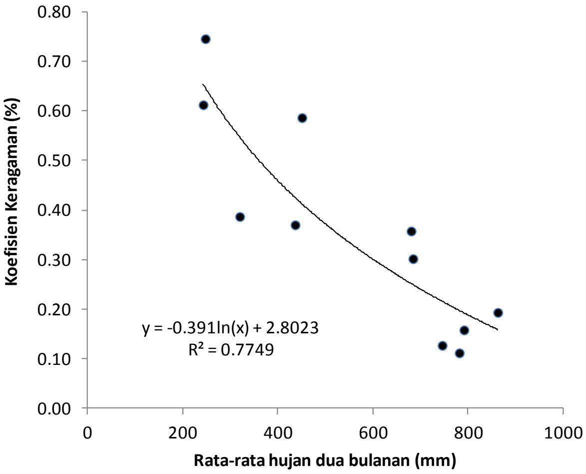


Figure 3-5: Relation between diversity coefficient (CV) and bi-monthly average rainfall in Palangkaraya (Note: CV = standard deviation/ average value)

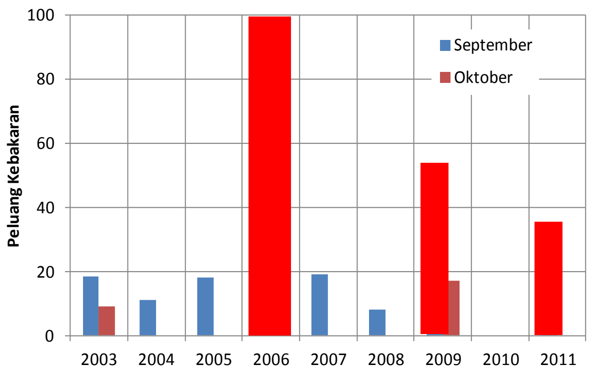


Figure 3-6: Estimation of forest fire in September and October based on bi-monthly rainfall information in July-August and August-September in Palangkaraya

In 2006 and 2009, El Nino impacted Indonesia. During the period, most Indonesian acreage include in Palangkaraya, experience drought due to below than normal rainfall (July-September). Meanwhile 2011 is the year of La Nina, when generally the level of rainfall in Indonesia was above normal during dry season. However, Palangkaraya experiences slightly lower than normal level of rainfall. This condition had caused fire risk prediction arise to approximately 30%. These results suggest that the policy makers should increase the wildfire critical value to be higher than 20%. In this case, 40% can be proposed as the critical value.

If critical value of 40% is accepted, then fire risk model to determine whether anticipation steps should be taken or not, must obey procedure as follows:

- Follow BMKG's bi-monthly rainfall forecast for every month.
- If rainfall on the next two months is predicted to be below normal, then find out BMKG's bi-monthly rainfall forecast and its margin error value.
- Utilize monthly rainfall forecast and its error value to perform Monte Carlo simulation on forest fire and the burned acreage.

If the final forecast value is greater than 40%, then the Government immediately must proceed the implementation of fire anticipation programs (two months earlier), particularly on fire-prone acreage. To make fire prevention model more effective, then fire-prone acreage need to be mapped.

In order to minimize forest/land fire risk and post burn impact, forest wardens should have adequate fire management system. Proper management system depends on an effective fire prevention, detection, and pre-disaster system, along with adequate fire extinguisher capabilities. Suggestions to be considered on forest/ land fire management include (Merril and Alexander, 1987):

- To strengthen risk reduction/ disaster mitigation preparedness through fire prevention activities aimed at reducing fire occurrence;

- Maintain state of readiness by implementing disaster mitigation activities prior to wildfire;
- Fast emergency response through fire spreading control and extinguish fire as soon as a flame detected; and To prepare recovery strategy after a fire.

Monte Carlo simulation is also used by Mason *et al.*, (2011) to estimate the amount of sediments due to erosion in Australia's southeast forest burned acreage, based on forest fire probability and precipitation. Mason *et al.*, (2011) combines some deterministic models to specify wildfire spread, erosion and sediment transfer process through annual Monte Carlo simulation of fire ignition and precipitation. By simulating fire behavior and analyzing historical data, it is possible to estimate the opportunity, expansion, and severity of wildfire. Furthermore, range of forest fire probability is combined with rainfall data to determine sediment of burned acreage. This model has also been applied on Upper Yarra and Thompson Riverbanks in Melbourne. Meanwhile, Carmel *et al.*, (2009) use Monte Carlo simulation to predict fire spreading model on Mt. Carmel, Israel. Carmel et al. (2009) utilize distribution map which consists data of possible forest fire occurrence, length of fire, fire locations, climate data, and other parameters (distance of fire ignition) which then are overlaid to generate hotspot and coldspot map of fire frequency. According to Carmel et al. (2009), Monte Carlo simulation of fire spread models can generate high-resolution map which may be used to plan long-term strategies for fire prevention activities.

4 CONCLUSION

Based on the analysis, it can be concluded that the best IRK variable to be used as precise estimator of burned acreage is the accumulation of rainfall 2 months prior to fire occurrence (CH2Bl) with the following equation: Wide range (Ha) = 5.1 – 21.7 X*, and X* = (CH2Bl - 93) mm with R2 of 67.2 %. Forest fire potential and its widespread can be determined by using Monte Carlo simulation based on the past two month rainfall. Any prevention efforts of forest fire should be prepared as early as possible, i.e. two months earlier when the fire risk value exceeds 40%.

To acquire a better model of forest fire widespread estimation and prediction, it takes more data which represent diverse conditions, both in terms of season and condition of the region.

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