International Journal on Advanced Science Engineering Information Technology

Vol.7 (2017) No. 2
ISSN: 2088-5334

The Investigation of 1997 and 2015 El Nino Events in West Sumatera, Indonesia

Revalin Herdianto[#], Elvi Roza Syofyan[#], Suhendrik Hanwar[#], Bambang Istijono[*], Dalrino[#]

[#]Department of Civil Engineering, Politeknik Negeri Padang, Limau Manis, Padang 25000, Indonesia
E-mail: revalin.herdianto@gmail.com, syofyan_er@yahoo.co.id, mr.suhendrik@gmail.com, dalrino350@gmail.com

[*]Faculty of Engineering, Andalas University, Limau Manis, Padang 25000, Indonesia
E-mail: bistijono1452@yahoo.co.id

***Abstract*— The 1997, 2010, and 2015 El Nino events have been recognized worldwide as a primary factor of decreasing biomass productivity. Its effects occur at farm as well as regional scale. Yet some still think that the effect is only perceived by farmers directly. We proposed a simple method to describe that its effect at catchment scale is not negligible. For this purpose, we analysed an upstream catchment in West Sumatera that normally receives high rainfall up to 5000 mm per year. This catchment is in pristine condition due to its status as a national park. We used satellite and ground monitoring systems *i.e.* rainfall and stream water level. Satellite data such as DEM (Digital Elevation Model) used to trace river networks is acquired from ASTER GDEM in 30 m resolution. To monitor vegetation health, we used NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) on board MODIS (MODerate resolution Imaging Spectroradiometer) Terra (daytime) MOD13Q1 (250 m resolution). Catchment delineation was performed using local land use map. Time series of EVI and NDVI was processed for the year 2015, comprising 23 datasets. Rainfall data from the year 1980 to 2012 from 9 stations and water level at the main river were analysed. We found the trace of 1997 El Nino very clearly through rainfall anomalies at all stations. As for the 2010 event, the pattern was not consistent across all rainfall stations. The 2015 event was not imminent until late October 2015. Throughout the year, NDVI remains above 0.8. In late October, maximum NDVI dropped below 0.4. This coincides with the very low water level in the stream. The same pattern was also found in two neighbouring catchments with similar land use, Kuranji and Air Dingin, and Tampo catchment. This proves that the 2015 El Nino did threatens not only farmers but also other aspects that depend on vegetation health and stream flow. Both methods are proven to be robust and may be used as an alternative way to monitor vegetation health and the impact of global climate change for ecology and water management such as domestic water use, irrigation, and flood control.**

***Keywords*— El Nino; DEM; NDVI; EVI.**

I. INTRODUCTION

In the last two decades, Indonesia has been hit by El Nino three times: in the year 1997, 2010 and recently in 2015. Unlike the 1997 and 2015 events, the 2010 event was less evident in Indonesia. El Nino is a global climate phenomenon marked by extreme climate events such as heavy rainfall, floods, and drought season. The latest event in 2015 affected at least 11 countries in Southeast Asia, including Indonesia [1]. In Indonesia, the most conspicuous effect is a long drought season throughout the country, particularly in Sumatera, the west-most island, and home of one of the largest tropical rainforest in the world. This effect is perceived primarily by farmers due to crop failures and forest fire. By non-farmers, El Nino effects are perceived in water scarcity for domestic uses and flushing pollutants in urban rivers. However, its indirect effect is not trivial to ecosystem health. Yet due to limited resources and technology, the impact of El-Nino events to the ecosystems are rarely monitored and documented by the local authority. This study aims to investigate the signs of the 1997 and 2015 El Nino in West Sumatera using two methods: hydrological parameters and vegetation indices for ecology and water management purposes.

Water in any forms is an essential factor for vegetation health and growth. Yet, due to inherently variable climate conditions, water is not always available in required amount and time. While excessive water can be damaging to vegetation, water shortage appears to be a more prominent threat to vegetation growth at higher altitude. Vegetation near a water source such as in riparian zone has an advantage compared to vegetation in the hillside, since soil moisture in the riparian zone lasts longer than at the hillside. Vegetation with longer and deeper root system may endure long drought compared to vegetation with short and shallow root system. These traits can be shown by vegetation in its resilience to short-term soil moisture variability.

Naturally, vegetation response to water shortage in several mechanisms such as by reducing stomatal opening [2], [3], [4], [5] which may lead to photosynthesis inhibition. Some vegetation use water more efficiently [6] to persist precipitation variability [7]. Different vegetation type exhibits some variation in water stress [8]. However, this response may not occur instantaneously due to other factors, such as deposit soil moisture, variable vegetation adaptation, and its relative position in topographic gradient. Recently, it was found that vegetation shows a hysteretic pattern in its response to annual rainfall [9] that may be an adaptation mechanism to water shortage.

In the past, the signs of vegetation response to water availability are difficult to observe, particularly at micro scale. Now, the advancement in remote sensing technology has enabled monitoring vegetation health and productivity using space-borne satellites which produce vegetation indices *e.g*. the Normalized Difference Vegetation Index (NDVI) which estimates the metric from reflectance at near infrared and red bands. NDVI is one of the most widely used vegetation indices although it carries some drawbacks such as early saturation in the thick canopy, atmospheric scattering effect due to aerosol particles, and canopy background reflectance. The EVI (Enhanced Vegetation Index) [10] addresses the NDVI issues by introducing reflectance at the blue band. Several studies have reported benefits of EVI than NDVI [11], [12]. Yet, the NDVI remains in use due to its simplicity and long history. Recently, Teoh *et al.* [13] used NDVI from a camera onboard an Unmanned Aerial Vehicle (UAV) to evaluate crop yield in Malaysia. The accuracy varied from 62 % to 96% between predicted and actual rice crop.

NDVI is defined as:

$$\mathrm{NDVI}=\frac{\rho_{NIR}-\rho_{Red}}{\rho_{NIR}+\rho_{Red}} \qquad (1)$$

and EVI is defined as:

$$\mathrm{EVI}=\frac{G(\rho_{NIR}-\rho_{Red})}{\rho_{NIR}+C_1\rho_{Red}-C_2\rho_{Blue}+L} \qquad (2)$$

The ρ_{Blue}, ρ_{Red}, and ρ_{NIR} are surface reflectance in the blue, red, and near-infrared bands, respectively; and G and L are the gain factor and canopy background adjustment parameter, respectively. C_1 and C_2 are coefficients for correcting aerosol influences in the red band by using the blue band. Adopted values used for G=2.5, L=1, C_1 = 6, and C_2 = 7.5. [9]. Both NDVI and EVI are acquired from MODIS (MODerate resolution Imaging Spectroradiometer) Terra land cover products.

II. Materials and Methods

A. Study Area and Rainfall Record

This study is conducted in the Province of West Sumatera. The area terrain is mainly hilly to mountainous with some flat terrain in the coastal area in the west. The province lies from 98.3-101.8 E and 1 N to -3.5 S with an area of 42,013 km^2. The west of the province directly faces the Indian Ocean, and the north, east, and south sides are placed among neighboring provinces. Land use is mostly forest, plantation, and farms, with the settlement, mostly inhabit lowlands and flood plains. We used two methods to observe the presence of El Nino in the year 1997 and 2015. The 1997 and 2010 events were analysed using rainfall data, and the 2015 event was analysed with stream flow and vegetation index. Rainfall data were collected from Provincial Office for Water Resources Management for 9 (nine) stations. Daily rainfall data are available at most stations from 1980 until 2011 or for 31 years. Some stations have a longer record up to 35 years. Location of the stations is presented in Fig. 1. Daily rainfall data was composited to annual rainfall. Average rainfall was calculated for the data span. Since rainfall variation is very large among the stations, rainfall anomalies are defined as annual rainfall above or below annual rainfall at each station.

Fig. 1 Study location in West Sumatra. Highlighted is the Province of West Sumatra

B. Vegetation Monitoring

Vegetation monitoring at catchment level was conducted at Arau catchment, at 100.454 E and 0.955 S. The catchment area is around 175 km^2 with an elevation between 0-2765 m above sea level. The upstream catchment is in pristine condition, dominated by evergreen trees and thick canopy and a part of the national park. The upper catchment is dominated by steep terrain up to 80^o. The main river is River Arau, stretches about 30 kilometers from east to west and ends at the Indian Ocean. Annual rainfall in the upper catchment reaches a maximum of 5000 mm and decreases to 3000 mm in the lower catchment. To represent catchment of natural rainforest, two catchments were used as a comparison: Kuranji and Air Dingin catchments in the north of Arau catchment. One catchment represents a non-natural catchment, Tampo catchment. This catchment is situated 62 km north-east Arau catchment. More than 80% of its area is occupied by settlement, paddy field, horticulture, and plantation. Farms in this catchment suffered from long drought until late 2015.

To monitor vegetation health, two MODIS products were used. The EVI and NDVI of 250 m resolution (MOD13Q1) in the year 2015 produced data every 16 days and acquired using MODIS Reprojection Tool (*MRTWeb*) [14]. The study catchments were delineated using land use map provided by Provincial Planning Board of West Sumatera. Time series of EVI and NDVI were processed and presented from Day of Year (DoY) 1 to DoY 353 with a 16-day interval. Both NDVI and EVI were presented as catchment average. Unlike the Arau catchment, EVI at Kuranji and Air Dingin was analysed on DoY 257, 273, 289, and 305, i.e. the period of apparent El Nino phenomenon. At Tampo catchment, EVI was used due to its advantage over NDVI in lands with some soil and water background. EVI time series was analysed in the whole year of 2015. To analyze catchment response to rainfall, water level data were acquired from Ministry of Public Works and Housing, Regional River Management Office Sumatera V in Padang. The daily water level is available for the year 2015.

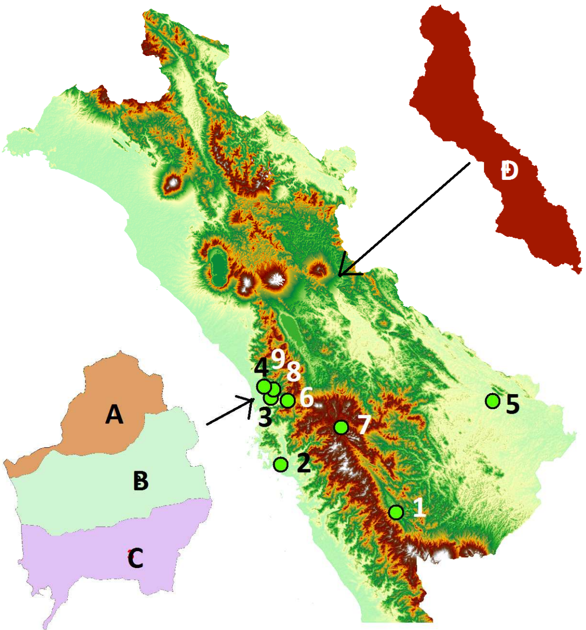

Fig. 2 Catchments used in the study: A. Air Dingin; B. Kuranji; C. Arau; D. Tampo, together with nine rainfall stations in West Sumatera Province. Name of rainfall stations are given in Table 1

C. Land Use Change

Land-use data were acquired from MODIS Land Cover from the year 2000 to 2012 using MODIS data interface (MRTWeb). Data are available in 500 m resolution. In MODIS MRTWeb, data for the study area are searched using interactive menu. Once the location is found, data are projected to designated projection system. In this study, we use the WGS84 coordinate system. Since one dataset occupied an area of 1200x1200 km, land cover data must be masked with studied catchment. Land cover classification is analyzed with MS Excel. MODIS land cover classification are as follows: evergreen needle leaf forest = 1;evergreen broadleaf forest = 2; deciduous needle leaf forest = 3; deciduous broadleaf forest = 4; mixed forests = 5; closed shrublands = 6; open shrublands = 7; woody savannas = 8; savannas = 9;grasslands = 10; croplands = 12; urban and built-up = 13; barren or sparsely vegetated = 16; unclassified = 254. An example of land use analysis for the year 2009 is presented in Fig. 3.

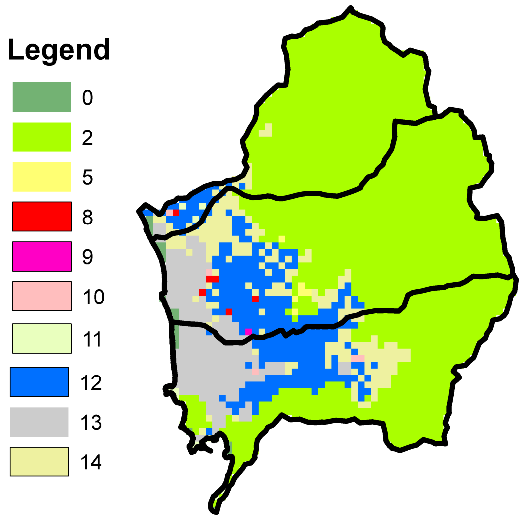

Fig. 3 An example of land use of Air Dingin, Kuranji, and Arau catchments in 2009

III. Results and Discussion

From nine rainfall recording stations, there are considerable variations in elevation and average rainfall Table 1). Average rainfall ranges from 1837 mm to above 4000 mm. Danau Diatas is located at the highest elevation among other stations, at 1534 m above sea level. At the same time, this station records the lowest rainfall among others. Stations located in the western part of Bukit Barisan (No. 2, 3, 4, 6, 8, 9) appear to have higher average rainfall than those on the eastern side due to the Indian Ocean effect.

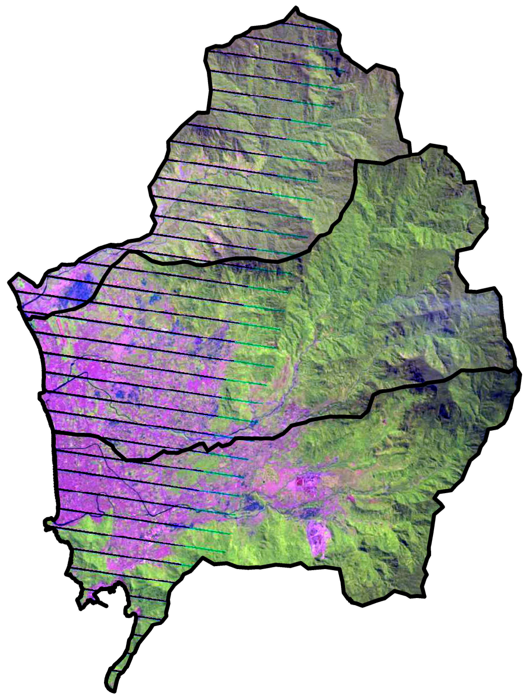

Fig. 4 Aerial image of Air Dingin, Kuranji, and Arau catchments. Source: Landsat 7 TM

TABLE I
RAINFALL RECORDING STATIONS

No	Station Name*	Station Lat-Lon	Elev (m)	Length of Record (Year)	Rainfall Average (mm)
1	Sungai Ipuh	01°28'48" S 101°.02'4" E	461	34	2,447
2	Tarusan	01°15'12" S 100°29'13" E	107	35	3,054
3	Gunung Nago	00°54'00" S 100°27'10" E	254	30	4,094
4	Simpang Alai	00°56'4" S 100°26'20" E	105	34	3,706
5	Pulau Punjung	00°57'8.8" S 101°29'34" E	114	18	3,361
6	Ladang Padi	00°56'55" S 100°31'8.8" E	625	34	3,861
7	Danau Diatas	01°04'40" S 100°46'20" E	1534	25	1,837
8	Batu Busuk	00°53'50"S 100°27'15" E	262	33	3,634
9	Koto Tuo	00°53'02" S 100°24'24" E	15	34	3,890

*Station names and numbers refer to Fig. 1.

The rainfall anomaly figures (Fig. 5) show that in all stations, the El Nino event in the year 1997 is clearly and consistently depicted. In all stations, annual rainfall is below average. Actually, rainfall below normal occurs in some other years but at local scale such as at catchment. From the year 1988 to 1994 for instance, station Ladang Padi experienced a long period of a negative anomaly for six consecutive years. Meanwhile, other stations in a radius of 10 kilometers such as Gunung Nago, Batu Busuk, and Simpang Alai showed some excess rainfall (positive anomaly) or only slightly below normal. A longer negative anomaly is observed at station Simpang Alai and Batu Busuk from 2003 to 2012, but a similar trend was not found at other stations. The most striking difference was observed at two neighboring stations, Ladang Padi and Batu Busuk from 1975 to 1978. At Batu Busuk station, a positive anomaly up to 4000 mm occurred in 1978 while at Ladang Padi station, a negative anomaly up to 1500 mm was observed at the same time. As noted in the beginning, the 2010 El Nino was not consistently shown by rainfall anomaly figures. In the year 2010, all stations in the west except Koto Tuo showed negative anomaly. Other stations, on the other hand, exhibited positive anomaly. In other words, the patterns are not consistent across the stations.

To investigate El Nino occurrence in 2015, a catchment in the western side of Bukit Barisan, Arau catchment, was analysed with NDVI and stream water level. Fig. 6 shows that both NDVI and stream level fluctuates throughout the seasons. NDVI value ranges from 0.6 to 0.9 from January to September. This is a common value for a thick rainforest canopy as found elsewhere. Fluctuation in rainfall does not immediately alter forest biomass, since mature trees may tap water from deeper soil layer. In a neighboring catchment of the Arau catchment, Sumani catchment, [15] found that vegetation index exhibited the same pattern with no linear correlation with stream flow. From September to late November, both NDVI showed a sudden drop to just over 0.2 before recovered again until December.

Like the NDVI, stream flow also fluctuated, but with a wider amplitude. It showed a minimum flow to almost zero in February, March, and May. Maximum flow occurred in August by 6 m. However, the water level graph showed little or no linear correlation with the NDVI. During peak water level in September, NDVI also showed its maximum at 0.9. Then from September to late October, both dropped at a similar rate, then recovered again until December. It is worth noting that the NDVI value presented here is catchment average and all pixels are in natural rainforest. At the other two neighboring catchments, Kuranji and Air Dingin, NDVI in the period observed also showed very similar values and trend.

Despite using a different indicator, the Tampo catchment exhibited very similar trend to the other three catchments (*i.e.* Arau, Kuranji, and Air Dingin). A minimum EVI occurred on DoY 289 by 0.15 (Fig. 6). On other DoY's, EVI fluctuated between 0.3 and 0.55. EVI values in Tampo are considerably lower than NDVI at Arau, Kuranji, and Air Dingin catchments. The first reason is that Tampo is dominated by farms and plantation, while Arau, Kuranji, and Air Dingin comprise thick canopy of the rainforest. At Tampo catchment, natural forest comprises only less than 15 percent of the catchment area, mostly on the west. The second reason is the inherently lower EVI value than the NDVI to inhibit early saturation in thick canopy.

At Arau catchment where the upper catchment is covered entirely by rainforest, the stream normally conserves some base flow for up to two weeks after rainfall events. Despite the steep slope, thick canopy and dense shrubs significantly delay peak flow. Yet long days without rainfall may have caused groundwater depletion. The water level in late October was the lowest in 2016. Our record shows that at station Ladang Padi (no. 6) in the central of upper Arau catchment, monthly rainfall in October varies between 290 to 700 mm. Yet in October 1997, it was only 30 mm, or the lowest in the same period from 1975-2012.

To confirm whether rainfall pattern in October is an annual trend or occasionally due to El Nino effect, we analysed monthly rainfall for this particular month from 1975 to 2012 at the Arau catchment. Fig. 5 shows that monthly rainfall in October fluctuates every year within a range of 30 to 1500 mm. Yet, in most years, the range is between 100 to 700 mm. In 2010, monthly rainfall in October was around 250 mm. The lowest rainfall was recorded in 1997 by 30 mm. This further reaffirmed the sign of El Nino in 1997

Similar rainfall-runoff pattern was also found in China in October [16] in which the decrease in precipitation coincides with the decrease in streamflow. Australia also showed peak dry season around September-October in the north-east. However, the patterns are not consistent throughout the continent with some lag effect between rainfall and runoff. The lag was thought to be the effect of soil and ground water storage. At the Arau catchment, there was no rainfall-runoff response analysis. Yet, the delay can be seen in Fig. 5 in the form of NDVI-streamflow level. It took about a month from a sudden drop in streamflow in September to a decrease of NDVI in October. Provided that most vegetation at the catchment are dominated by trees aged more than 50 years, the delayed response may confirm the effect of ground water storage.

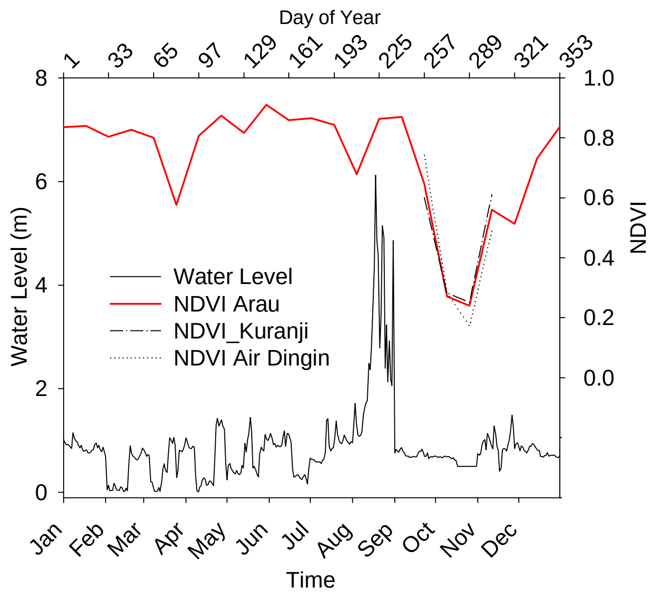

Fig. 5 NDVI seasonality at three catchments and water level at Arau River

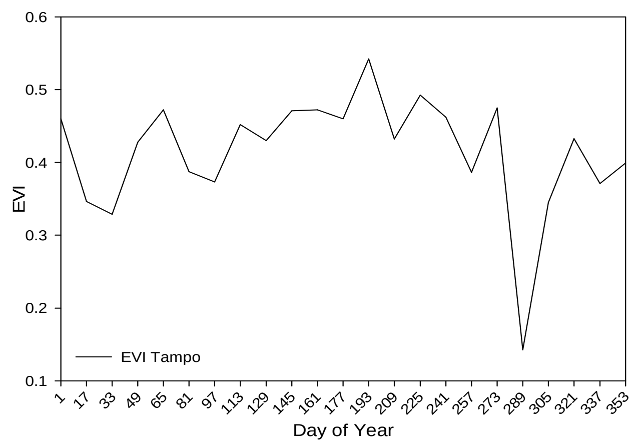

Fig. 6 EVI seasonality at Tampo catchment in 2015

The changes in streamflow are highly affected by human activities, such as changes in land use which eventually lead to increased runoff. However, this is unlikely the case for Arau catchment since land use has not changed much, as of the Kuranji catchment [17]. This case might be true for the Tampo catchment since most of the middle catchment is devoted to farms and settlement. In these three catchments (Arau, Kuranji, Air Dingin) (Fig. 8) the highest portion of the catchments is an evergreen forest by above 17000 hectares. This figure even increased from 2002 to 2009 before a small decrease afterward. Other types of land cover occupy less than 5000 hectares and have not changed much during this period. Therefore, the sudden decrease in streamflow in the Arau catchment is likely attributed to the decrease in precipitation, as also confirmed by the NDVI figure.

The impact of 2015 El Nino was not only perceived in Indonesia. A similar decrease in rainfall prior to El Nino events was observed in Korea [18]. Apart from a long drought in Indonesia, El Nino also causes the opposite effects elsewhere. Ward et al (2016) found by simulation that El Nino events tend to increase not only flood prevalence but also flood duration. In Brazil, El Nino event tends to increase soil erosivity [19]. Since the main stream of the Arau catchment flows through the heart of the City of Padang, its functions as the source of domestic water and for drainage are vital for the city. It is very important to maintain the water level at a safe stage for flushing and flood control. At Kuranji and Air Dingin catchments, apart from these functions, the streams also serve as irrigation for approximately 2000 hectares of paddy farms. The long drought in last October certainly reduces productivity.

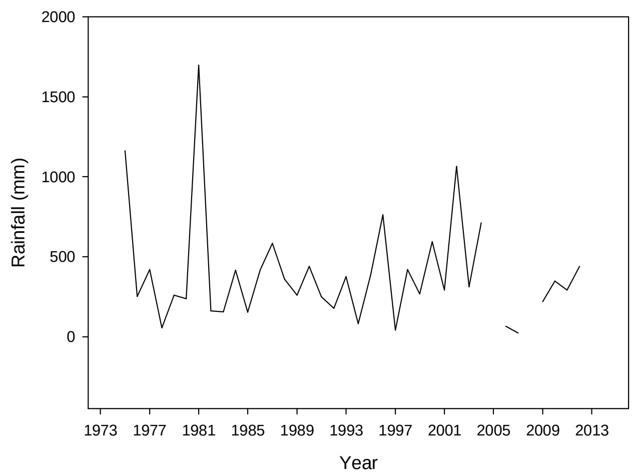

Fig. 7 October rainfall at Arau catchment (1974-2012)

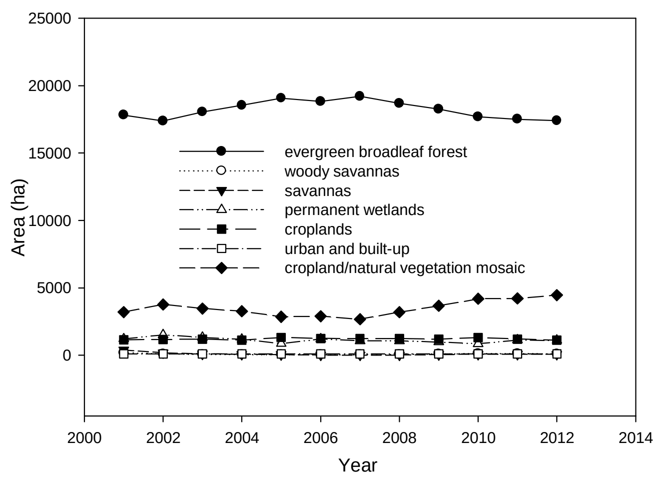

Fig. 8 Land use changes at Arau, Kuranji, Air Dingin catchments, Year 2000-2012

IV. Conclusions

We analysed El Nino events in 1997 and 2015 using two different approaches; the 1997 event was analysed with rainfall, and the 2015 event was analysed with stream flow and vegetation indices. Both methods, at least in our study, have been proven to be robust to detect the occurrence of the El Nino events in 1997 and 2015. Both methods are complementary each other, depending on data availability. However, the use of vegetation indices prior to the year 2000 is limited by the absence of EVI, whereas the NDVI that have been used since 1980's have shown its limitation.

The 2010 El Nino event, as noted in the beginning, was not consistently shown by rainfall anomaly data. Although the event was reported elsewhere, this study has shown that its presence was not pronounced, at least in the studied catchments. This might be the reason that the event was less concerned in Indonesia compared to the other two events in 1997 and 2015.

The EVI and NDVI, once again, have been proven as a powerful tool for monitoring vegetation health as a signal for catchment response to incoming water, as observed in a Korean deciduous forest [15]. Coupled with hydrological data, these indices may serve as a key predictor of ecosystem response to climate changes for water management.

REFERENCES

[1] El Niño in Asia, http://www.unocha.org /elninoasia. [21 October 2016].

[2] Davies, W.J.,Kozlowski, T.T., 1974, 'Stomatal responses of five woody angiospasms to light intensity and humidity', *Canadian Journal of Botany*, vol. 52, no. 7, pp. 1525-1534.

[3] Grace, J., Malcolm, D.C., Bradbury, I.K., 1975, 'Effect of Wind and Humidity on Leaf Diffusive Resistance in Sitka Spruce Seedlings', *Journal of Applied Ecology*, vol. 12, no. 3, pp. 931-940.

[4] Schulze, E.D., 1986, 'Carbon-Dioxide and Water-Vapor Exchange in Response to Drought in the Atmosphere and in the Soil', *Annual Review of Plant Physiology and Plant Molecular Biology*, vol. 37, pp. 247-274.

[5] Myers, B.J., 1988, 'Water stress integral—a link between short-term stress and long-term growth', *Tree Physiology*, vol. 4, no. 4, pp. 315-323.

[6] Troch, P.A., Martinez, G.F., Pauwels, V.R.N., Durcik, M., Sivapalan, M., Harman, C., Brooks, P.D., Gupta, H., Huxman, T., 2009, 'Climate and vegetation water use efficiency at catchment scales', *Hydrological Processes*, vol. 23, pp. 2409-2414.

[7] Smettem, K.R., Waring, R.H., Callow, J.N., Wilson, M., Mu, Q., 2013, 'Satellite-derived estimates of forest leaf area index in southwest Western Australia are not tightly coupled to interannual variations in rainfall: implications for groundwater decline in a drying climate', *Glob Chang Biol*, vol. 19, no. 8, pp. 2401-12.

[8] Nasiri, M., Zarehaghi, D., Neyshabouri, M.R., 2016,'Some Weeds Community Percent in Response to Pumice Application on Soil under Water Stress Conditions', IJASEIT, vol. 6. no. 2.

[9] Herdianto, R., Paik, K., Coles, N., Smettem, K.J., 2013, 'Transitional responses of vegetation activities to temperature variations: Insights obtained from a forested catchment in Korea', *Journal of Hydrology*, vol. 484, pp. 86-95.

[10] Huete, A.R, Liu, H.Q., Batchily, K., vanLeeuwen, W., 1997, 'A comparison of vegetation indices global set of TM images for EOS-MODIS', *Remote Sensing of Environment*, vol. 59, no. 3, pp. 440-451.

[11] Huete, A., Didan, K., Miura, T., Rodriguez, E.P., Gao, X., Ferreira, L.G. 2002, 'Overview of the radiometric and biophysical performance of the MODIS vegetation indices', *Remote Sensing of Environment*, vol. 83, pp. 195-213.

[12] Evrendilek, F., Gulbeyaz, O., 2008, 'Deriving Vegetation Dynamics of Natural Terrestrial Ecosystems from MODIS NDVI/EVI Data over Turkey', *Sensors*, vol. 8, pp. 5270-5302.

[13] Teoh, C.C., Mohd Nadzim, N., Mohd Shahmihaizan, M.J., Mohd Khairil Izani, I, Faizal, K., Mohd Shukry, H.B., 2016, 'Rice Yield Estimation using Below Cloud Remote Sensing Images Acquired by Unmanned Airborne Vehicle System', *IJASEIT*,vol.6 no. 4.

[14] USGS, *MODIS Reprojection Tool Web Interface (MRTWeb)*. available from: <https://mrtweb.cr.usgs.gov/>. [12 February 2011].

[15] Herdianto, R., Paik, K., Coles, N., Smettem, K.J., 2010, 'Coupling vegetation index and terrain information for better representation of spatial and temporal dynamics of hydrological processes', Proceedings 8th Symposium on Ecohydraulics.

[16] Guo, A., Chang, J., Liu, D., Wang, Y., Huang, Q., Li, Y., 2016, 'Variations in the Precipitation-Runoff relationship of the Weihe River Basin', *Hydrology Research* nh2016032. DOI: 10.2166/nh.2016.032.

[17] Herdianto, R., 2016, Finding the cause of 2012-2016 flash flood in West Sumatra: on and above ground monitoring, *Proceedings of 13th AOGS Annual Meeting*, Beijing, August 2016.

[18] Lee, J.H., Julien, P.Y., 2016, 'Teleconnections of the ENSO and South Korean precipitation patterns', *Journal of Hydrology*, vol. 534, March 2016, pp. 237-250, ISSN 0022-1694, http://dx.doi.org/10.1016/j.jhydrol.2016.01. 011

[19] Mello, C. R., Norton, L. D., Curi, N., Yanagi, S. N. M., Silva, A. M., 2011,'El-Ni˜no southern oscillation and rainfall erosivity in the headwater region of the Grande River Basin, Southeast Brazil', *Hydrol. Earth Syst. Sci. Discuss*. 8, 10707–10738.