RESPONSE OF SATELLITE-DERIVED AGRICULTURAL DROUGHT INDEX ON THE DIFFERENT METEOROLOGICAL PARAMETERS

Angelo Benedict R. Ragunjan[1,2] and Gay Jane P. Perez[1]
[1]Institute of Environmental Science and Meteorology
University of the Philippines-Diliman, Quezon City, Philippines
[2]Mariano Marcos State University
Batac, Ilocos Norte, Philippines
Email: instructorgelo@yahoo.com, gpperez1@up.edu.ph

KEY WORDS: drought, agriculture, logistic regression, Philippines

ABSTRACT

Drought is generally characterized by the relatively low rainfall amount over a period that affects not only the agricultural sector but also the economic sector in the Philippines. In this study, different meteorological parameters, such as evapotranspiration, potential evapotranspiration, land surface temperature, and rainfall, were linked to the satellite-derived agricultural drought index. The agricultural drought was assessed using the Standardized Vegetation-Temperature Ratio, an index based on satellite-derived land surface temperature and vegetation. Logistic regression was applied to identify the individual influence of the different meteorological parameters in the occurrence of agricultural drought. Results show that evapotranspiration and rainfall are both positively correlated to agricultural drought, while negative correlations were found for land surface temperature and potential evapotranspiration. Using logistic regression analysis, evapotranspiration was found to have the strongest influence on an existing agricultural drought. The effects of rainfall on the agricultural drought increases with time, which signifies lag effect of rainfall on the development of agricultural drought.

1. INTRODUCTION

Drought is mainly caused by an occasional low amount of rain compared to the normal value over an extended period. One of the climate drivers that affect rainfall, which would also cause drought in the Philippines, is the El Niño Southern Oscillation (ENSO). The extreme phases of ENSO have a strong effect on the seasonal rainfall in the Philippines, with ENSO warm events (El Niño) often associated with droughts and stresses on water resources (Jose 2002, Lyon et al., 2006). Drought occurrences in the Philippines of different intensities, durations, and impacts were recorded in 1982-83, 1986-87, 1989-90, 1991-92, 2002-03, 2004-05, 2007, 2009-10, and 2014-16, all of which coincide with ENSO years (Hilario et al., 2009; Yumul et al., 2010).

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the country's weather bureau, monitors, and issues El Niño advisories to the country. The PAGASA uses the Percentage of Normal Precipitation (PN) and Standardized Precipitation Index (SPI) in drought monitoring. The PN is one of the simplest index (Wilhite, 2011) and most straightforward measures of rainfall deviation from its long-term average value (Morid, 2006). Using the criteria set by PAGASA, drought is defined as 3-consecutive months of way below normal condition (>60% reduction from average rainfall), dry spell occurs when 3-consecutive months of below normal rainfall condition, and dry condition when 2-consecutive months of below normal rainfall condition. Aside from PN, the PAGASA is also using SPI, which can describe precipitation shortages on any time scale and allows drought to be readily identified and monitored for its duration (Hayes, et al., 1999). The agricultural sector in the Philippines relies on the advisories given by PAGASA for drought monitoring. However, there are inherent limitations since PAGASA are observing meteorological drought, which does not always coincide with periods of agricultural droughts (Wilhite and Glantz, 1985).

Low rainfall amounts leading to drought is not only triggered by El Niño events that essentially draw rain clouds away from the Philippines, but also by other factors such as lower monsoonal rainfall amounts and warmer temperatures. Other meteorological factors could contribute to the intensity of drought, such as the evapotranspiration (ET), which is a major component of the water budget for agricultural crops. ET is the combined process of evaporation from the water surface, soil moisture, and plant and it expresses the exchange of mass and energy between the soil–water–vegetation system and the atmosphere (Tadesse, et al., 2015). Monitoring ET is important, especially as the water resources become limited due to potential climate change, competition from other water users, increasing population, drought, and decreasing water quality (Farahani et al., 2007, Suyker, et al., 2008). Some studies are using evapotranspiration data as a proxy for vegetation condition monitoring.

A satellite-derived localized agricultural drought index called the Standardized Vegetation-Temperature Ratio (SVTR) was developed based on the NDVI-LST relationship, which can provide alternative information for soil moisture (Perez, et al., 2016; Son, et al., 2012). Monthly MODIS Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST) products with 5.6 km spatial resolution were used to calculate and produce monthly SVTR values (Perez, et al., 2016). Negative SVTR values denote areas with dry conditions. The satellite-derived SVTR was found to be 73% accurate in detecting agricultural drought. The SVTR showed high positive correlation with the Evaporative Stress Index (ESI), the USDA's agricultural drought index, particularly during the dry months and in the croplands.

In this study, the primary goal is to identify the response of agricultural drought to the different meteorological parameters, such as evapotranspiration, potential evapotranspiration, land surface temperature, and rainfall in the Philippines. The agricultural drought events were assessed using the Standardized Vegetation-Temperature Ratio, an index based on satellite-derived land surface temperature and vegetation.

2. METHODOLOGY

2.1. The Study Area

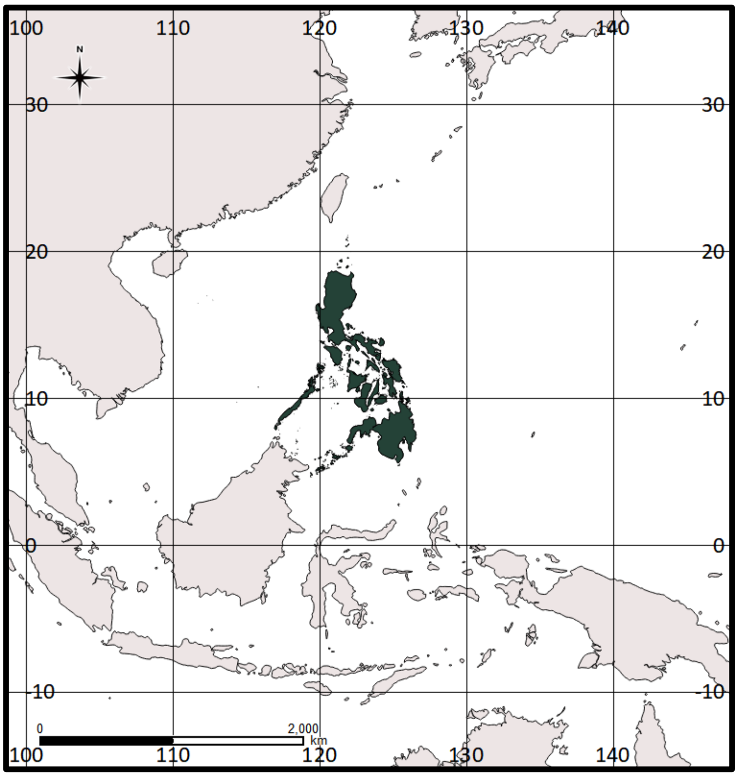

Figure 1. The Philippines.

The Philippines (Figure 1) is an archipelago geographically located between latitude 4°23'N and 21°25'N and longitude 116°E and 127°E. The country has an approximate total land area of 300,000 square kilometers or 30 million hectares. The topography and geographical position of the Philippines affect the climatic and vegetative conditions of the country.

About 32 percent of the country's total land area is agricultural lands. The country's labor force in 2015 totaled 41.34 million persons with the agriculture sector employed 11.29 million persons, which comprised 29 percent of the national employment, about P114.46 billion were spent by the government for the agriculture sector or 4.39 percent of the total national expenditures (PSA, 2016).

The spatial and temporal distribution of rainfall in the Philippines is uneven where some areas are receiving more rainfall and at a higher frequency than other areas. Based on rainfall distribution, the country has four different climate types (Coronas, 1918). Areas belonging to climate type 1 has pronounced wet and dry season since areas within this climate type are shielded from the northeast monsoon but are open to the southwest monsoon. The climate type 2 areas have no dry season but a pronounced maximum rain period during the months of December to February since it is open to the northeast monsoon and trade winds or from cyclonic storms. Areas within climate type 3 have no pronounced maximum rain period and short dry season lasting from one to three months only due to being partly sheltered from the northeast monsoon and trade winds and open to the southwest monsoon or at least to frequent cyclonic storms. And climate type 4 areas have uniformly distributed rainfall. The areas affected receive the most moderate effects of the northeast monsoon and trade winds as well as the southwest monsoon and cyclonic storms. Topography is the main reason for this difference in climate types.

2.2. The Agricultural Drought Index

The agricultural drought was assessed using the satellite-derived drought index, the Standardized Vegetation-Temperature Ratio (Perez, et al., 2016). It was calculated using the equation:

$$SVTR = \frac{R_i - \overline{R}_i}{\sigma_{R_i}} \tag{1}$$

where, R_i stands for the ratio of NDVI to LST for the month i, $\overline{R}_i$ represents the monthly climatology of R, and σ_{R_i} refers to standard deviation of R for month i. Negative SVTR values indicate drought-affected areas, while positive values denote areas with moist conditions.

2.3. The Meteorological Parameters

To identify the response of agricultural drought to the different meteorological parameters, four (4) meteorological parameters were considered - rainfall, land surface temperature, evapotranspiration, and potential evapotranspiration.

Daily precipitation data with 0.25° latitude by 0.25° longitude spatial resolution from January 01, 2002 to December 31, 2016, was derived from TRMM 3B43. The TRMM 3B43 is created using TRMM-adjusted merged microwave-infrared precipitation rate (in mm/hr) and root-mean-square (RMS) precipitation-error estimates and it provides the best precipitation estimate in a latitude band covering 50° N to 50° S, an expansion of the TRMM region, from all global data sources, namely high-quality microwave data, infrared data, and analyses of rain gauges. The data were resampled to 0.05° latitude by 0.05° longitude to allow correlation of different datasets.

The monthly land surface temperature data was derived from MODIS Land Surface Temperature (LST) product with a spatial resolution of 0.05° latitude by 0.05° longitude from January 2002 to December 2016. The MOD11C1 was retrieved from https://lpdaac.usgs.gov, maintained by the NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC) at the USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota.

Monthly evapotranspiration and potential evapotranspiration data were derived from the MODIS Evapotranspiration product with a spatial resolution of 0.01° latitude by 0.01° longitude from January 2002 to December 2014. The monthly data was downloaded from the Numerical Terradynamic Simulation Group (NTSG) public data repository at files.ntsg.umt.edu. The MOD16 algorithm is based on the logic of the Penman-Monteith equation which uses daily meteorological reanalysis data and 8-day remotely sensed vegetation property dynamics from MODIS as inputs. The data were resampled to 0.05° latitude by 0.05° longitude to allow correlation of different datasets.

2.4. Statistical Analysis

2.4.1.Correlation Analysis

To determine the influence of meteorological parameters to the agricultural drought, correlation maps were created for each meteorological parameter. The Pearson correlation was used to measure the strength and direction of the linear relationship of the meteorological variables to SVTR. The Pearson correlation coefficient has a value from -1 to +1, where a +1 value shows a perfect linear relationship, a -1 value shows a perfect inverse relationship and a 0 value shows a nonlinear relationship. In this study, the correlation coefficient with a value less than 0.25 was considered as low correlation, a correlation coefficient from 0.25 to 0.50 as moderate correlation, and a correlation coefficient greater than 0.50 shows a high correlation. The response of agricultural drought from the previous monthly values of the meteorological parameters was also identified by conducting correlations for varying time lags (from none to 12-month lag).

2.4.2. Logistic Regression

The multinomial logistic regression was used to identify variables which are most likely to predict the occurrence of agricultural drought. The multinomial logistic regression model uses a binary or dichotomous predictand and continuous variables, categorical variables, or both independent predictors. Like the linear regression, one estimates the relationship between predictor variables and an outcome variable. However, in logistic regression, the probability that the outcome variable was estimated and not the actual value itself.

Using the SVTR values, drought and non-drought events were identified. Among the parameters used to predict agricultural drought occurrences were the standardized rainfall anomaly, standardized evapotranspiration anomaly, standardized potential evapotranspiration anomaly, and standardized land surface temperature anomaly.

3. RESULTS AND DISCUSSIONS

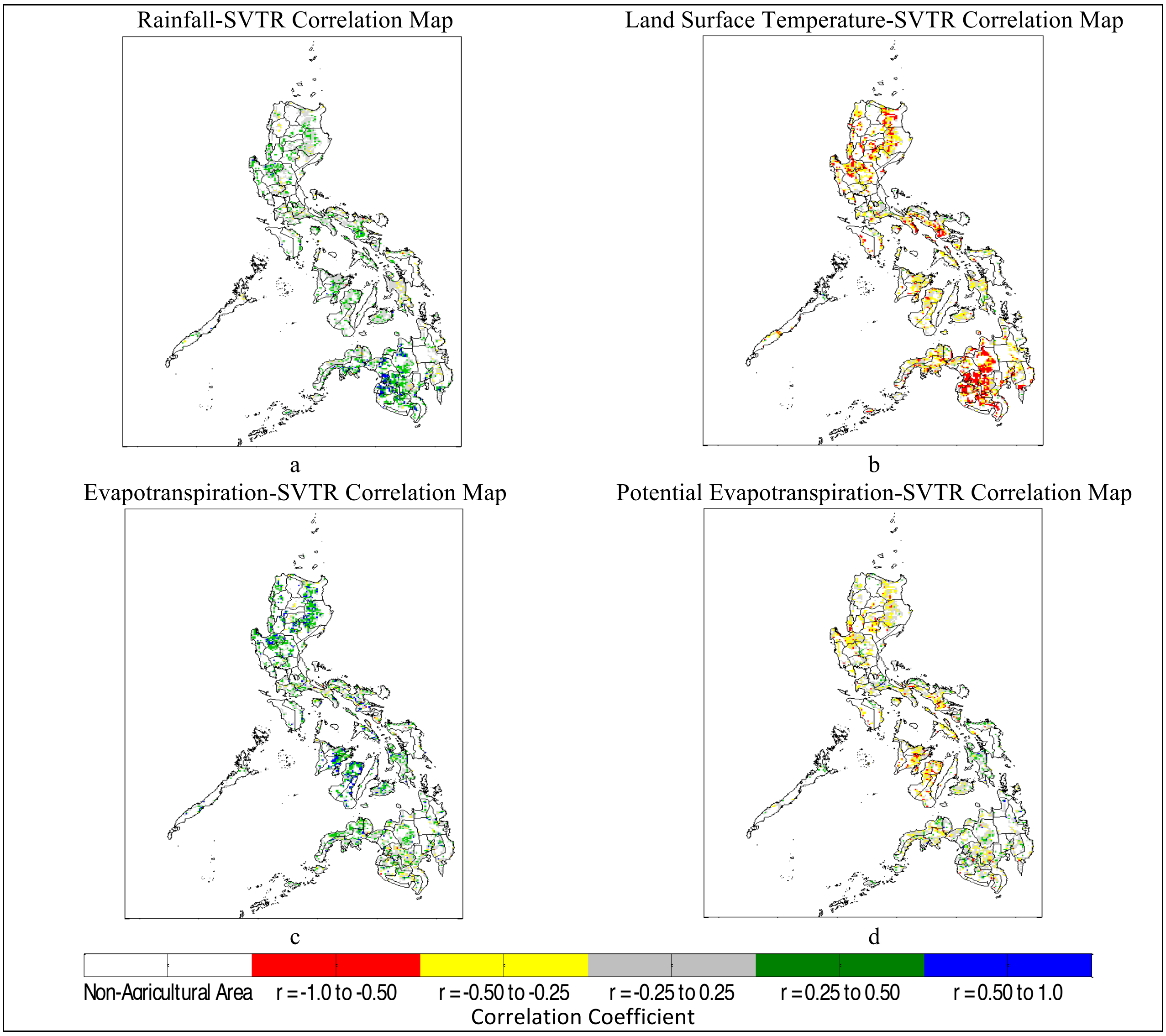

Figure 2. Correlation Maps of Meteorological Parameters and Agricultural Drought Index, SVTR, during Drought Events. Meteorological parameters considered were (a) rainfall, (b) land surface temperature, (c)evapotranspiration, and (d) potential evapotranspiration.

The results showed an overall positive correlation between the SVTR and standardized rainfall anomaly (Figure 2a). This result proved that rainfall deficit (negative rainfall anomaly) could lead to agricultural drought (negative SVTR). The meteorological drought was manifested by rainfall deficit; thus, the meteorological drought could lead to agricultural drought. Similarly, Dhakar, et al. (2013) found significant linear relationships between agricultural drought index, NDVI, and rainfall anomaly. They added that during low rainfall years, vegetation condition was also low and during high rainfall years, vegetation condition was also high.

Results also revealed that negative relationship between land surface temperature and SVTR (Figure 2b) was found. This result shows that negative SVTR values coincide with positive land surface temperature anomaly. It is evident that during agricultural drought event, there was an increased land surface temperature. Similar results were found by Karnieli, et al. (2009) where an agricultural drought indicator is negatively correlated with LST for low latitudes which resulted from the cooling effects of canopy transpiration.

Furthermore, a positive correlation between evapotranspiration anomaly and SVTR (Figure 2c) was found during the agricultural drought events in the Philippines. This implies a decrease in evapotranspiration rate during the agricultural drought events. In the study of Zhang, et al. (2004), soil water deficit, which experienced during drought events, significantly reduced evapotranspiration, compared with normal soil water condition and the transpiration by plants may decrease as plants attempt to conserve water (Hanson, 1991).

Finally, a negative correlation was found between potential evapotranspiration anomaly and SVTR (Figure 2d). Potential evapotranspiration is defined as the demand or maximum amount of water that would be transpired if enough water from precipitation and soil moisture is available (US-NOAA). The negative correlation reflects the increase in water demand during agricultural drought events. During drought events, a dry condition is usually expected together with dry soil moisture and lesser rainfall. Interestingly, areas with negative correlation are the same with high variability in land surface temperature. According to Rind, et al. (1990), potential evapotranspiration increases most in areas where the temperature is highest. Furthermore, vegetation and climate models (Rind, et al., 1990) show that large potential evapotranspiration changes can result in soil moisture deficits and vegetation scarcity.

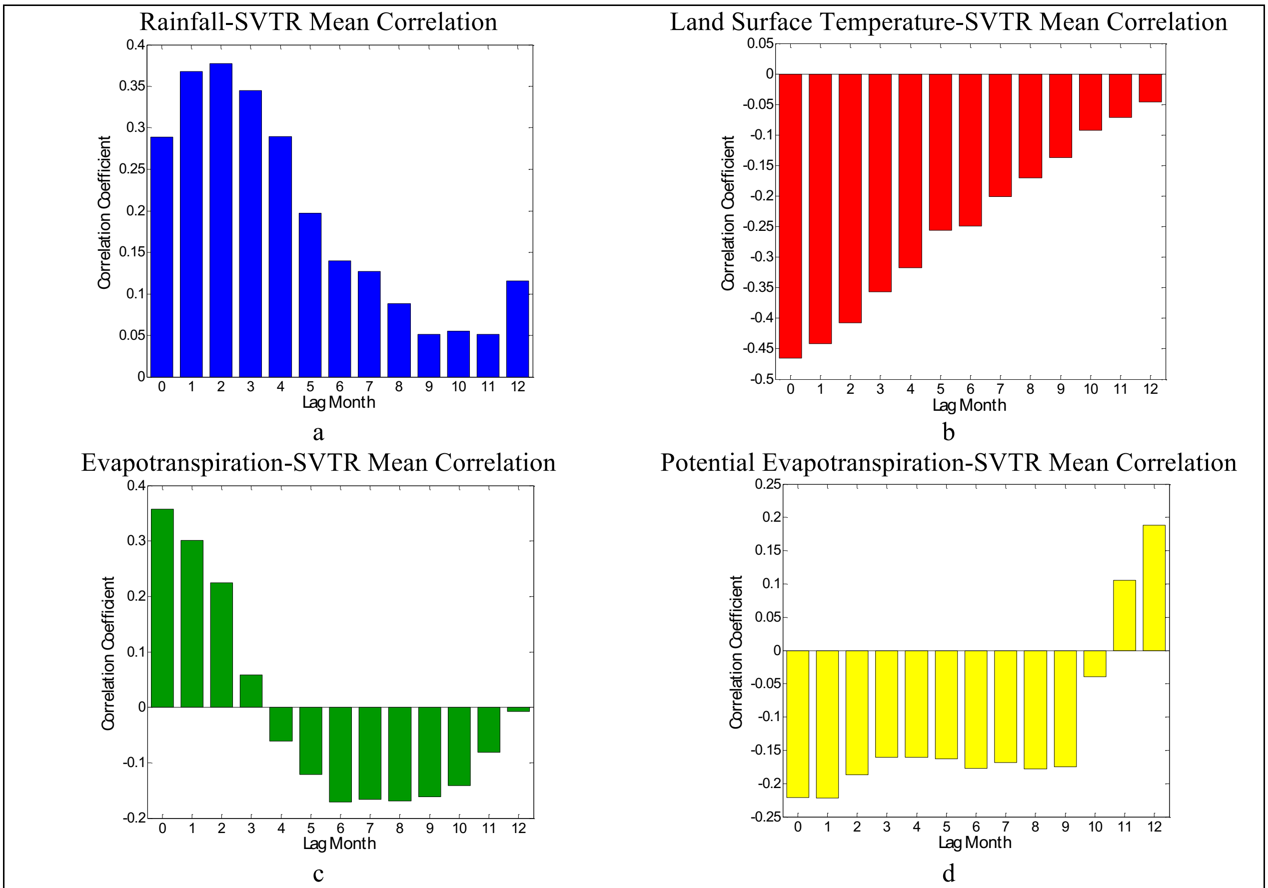

Figure 3. Mean Correlation Coefficient the Different Month Lag for SVTR and (a) rainfall, (b) land surface temperature, (c) evapotranspiration, and (d) potential evapotranspiration.

To better understand the impact of each meteorological parameters on the development of agricultural drought, each meteorological parameter was correlated to SVTR at a different lag time prior to the development of agricultural drought. The effect of rainfall anomaly on SVTR increases as the lag month increases up to 2-month lag (Figure 3a). The increased r-value implies a better response to agricultural drought into rainfall deficit. The effect of rainfall deficit on the development of agricultural drought was delayed up to 2 months. This shows that meteorological drought occurred first before the agricultural drought, and the termination of meteorological drought does not necessarily mean the end of the agricultural drought event.

On the other hand, the highest correlation coefficient of land surface temperature and SVTR (Figure 3b) was found during the 0-month lag. The effect of high land surface temperature on agricultural drought decreases as the lag increases. This means that land surface temperature has the highest impact on agricultural drought development on the same month. The agricultural drought was still affected by previous land surface temperature. Similarly, the same result is seen for the effect of evapotranspiration on SVTR (Figure 3c). Highest correspondence of evapotranspiration rate agricultural drought was found on the same month and it decreases as the lag month increases. For potential evapotranspiration (Figure 3d), an almost equal mean correlation coefficient was found during the 0-lag month and 1-month lag. This implies that the effect of water demand on agricultural drought event could extend for the following month. This result can suggest that if continuous water demand cannot be supplied by rainfall, agricultural drought condition may develop or aggravate. If precipitation cannot keep pace with the high water demand due to warming land surface, drought condition will escalate (Rind, 1990).

To determine the meteorological parameter that could best predict the occurrence of agricultural drought, the logistic regression analysis was employed (Figure 4). Overall, most areas show that evapotranspiration to have the greatest influence in the occurrence of agricultural drought in the Philippines during the same month. With respect to the previous months, more areas are showing rainfall as the main predictor of agricultural drought. Compared to the 0-month lag and 2-month lag, more areas are showing rainfall (blue pixel) than evapotranspiration (green pixel) as the meteorological drought that could trigger agricultural drought. Also, the effect of land surface temperature (red pixel) was higher prior to the development of agricultural drought than the evapotranspiration.

Results show that the effect of rainfall do not immediately contribute to the development of agricultural drought but it took longer time for rainfall to influence the formation or intensifying agricultural drought. The amount of rainfall was stored in plant cells and as soil moisture for a couple of months and if the evaporation rate was greater than the stored moisture, agricultural drought may occur.

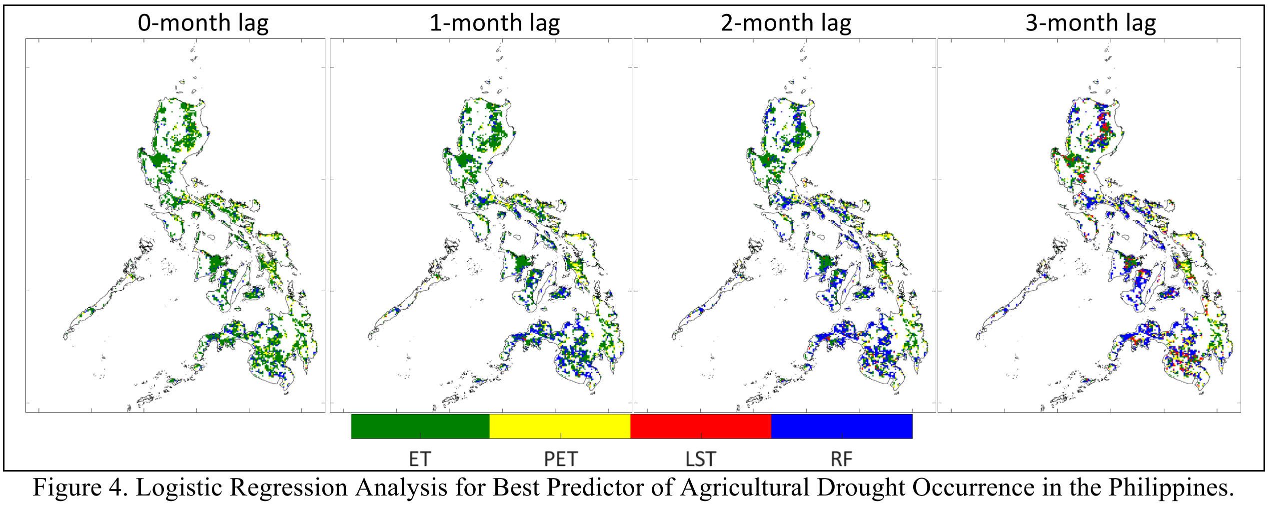

Figure 4. Logistic Regression Analysis for Best Predictor of Agricultural Drought Occurrence in the Philippines.

4. CONCLUSION

The effects of meteorological parameters on agricultural drought in the Philippines were evaluated. Agricultural drought was shown to be influenced by rainfall deficit and increased land surface temperature. Also, agricultural drought was characterized by low evaporation rate from soil and plants. The increased water demand can also trigger agricultural drought in the Philippines. The influence of rainfall was found to be highest two (2) months prior to the occurrence of agricultural drought and up to one (1) month for potential evapotranspiration. Also, a direct effect of land surface temperature and evapotranspiration to the agricultural drought was found. The current condition of agricultural drought event in the Philippines was greatly influenced by the evapotranspiration rate and the previous rainfall deficit. The delayed effect of rainfall on agricultural drought formation found in the study shows the importance of understanding the influence of other meteorological variables on dynamics of drought and crop water management.

5. RECOMMENDATIONS

Drought intensity was also projected to increase if the current trend of warming continues. Results of this study can be a guide to anticipate the probability of agricultural drought onset based on the condition of different environmental factors such as rainfall, land surface temperature, evapotranspiration, and potential evapotranspiration. Further studies may consider other meteorological parameters gathered through on-site observations. Analyzing the return period of meteorological drought and agricultural drought and assessing the agreement of the return periods are also recommended. Also, it is recommended to find the influence of meteorological drought and agricultural drought on cropping season.

REFERENCES

Dhakar, Rajkumar. et. al. 2013. Study on inter-seasonal and intra-seasonal relationships of meteorological and agricultural drought indices in the Rajasthan State of India. Journal of Arid Environments 97 (2013) 108-119.

Farahani, HJ, TA Howell, WJ Shuttleworth, and WC Bausch, 2007. Evapotranspiration: Progress in Measurement and Modeling in Agriculture. 2007 American Society of Agricultural and Biological Engineers ISSN 0001-2351. Vol. 50(5): 1627-1638.

Hanson, Ronald L. 1991. Evaporation and Droughts. Retrieved April 24, 2017 from https://geochange.er.usgs.gov/sw/changes/natural/et/

Hayes, Michael J., Mark. D. Svoboda, Donald A. Wilhite, and Olga V. Vanyarkho, 1999. Monitoring the 1996 drought using the standardized precipitation index. Bulletin of the American Meteorological Society 80, 429-438.

Hilario, Flaviano, Rosalina de Guzman, Daisy Ortega, Peter Hayman, and Bronya Alexander, 2009. El Niño Southern Oscillation in the Philippines: Impacts, Forecasts, and Risk Management. Philippine Journal of Development.

Jose, A.M. 2002. ENSO impacts in the Philippines: examples of ENSO-society interactions. Retrieved May 15, 2017 from http://iri.columbia.edu/climate/ENSO/societal/example/Jose.html.

Karnieli, A., N. Agam, R.T. Pinker, M. Anderson, M.L. Imhoff, G.G. Gutman, N. Panov, and A. Goldberg, 2010: Use of NDVI and Land Surface Temperature for Drought Assessment: Merits and Limitations. *J. Climate,* 23, 618–633.

Keyantash, J.,Dracup, J.A., 2002. The Quantification of Drought: An Evaluation of Drought Indices. Bulletin of the American Meteorological Society 83 (8),1167-1180.

Lyon, B., H. Cristi, E.R. Verceles, F.D. Hilario, and R. Abastillas. 2006. Seasonal reversal of the ENSO rainfall signal in the Philippines. Geophysical Research Letters 33:L24710.

Morid, Saeid, Vladimir Smakhtin and Mahnosh Moghaddasi., 2006. Comparison of seven meteorological indices for drought monitoring in Iran. International Journal of Climatology 26(7):971 – 985

Perez, Gay Jane P. M. Macapagal, R. Olivares, E. M. Macapagal, J. C. Comiso, 2015. Forecasting and Monitoring Agricultural Drought in the Philippines. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B8, 2016.

Philippine Statistics Authority. 2016. Selected Statistics on Agriculture 2016. Retrieved August 30, 2017, from https://psa.gov.ph/sites/default/files/Selected%20Statistics%20on%20Agriculture%202016.pdf.

Rind, D. et al. (1990). Potential evapotranspiration and the likelihood of future drought. Retrieved April 27, 2017 from http://onlinelibrary.wiley.com/doi/10.1029/JD095iD07p09983/full.

Son, N. T., et al., 2012. Monitoring agricultural drought in the Lower Mekong Basin using MODIS NDVI and land surface temperature data. International Journal of Applied Earth Observation and Geoinformation 18 (2012) 417–427.

Suyker, et al., 2008. Evaporation of irrigated and rainfed maize-soybean cropping systems. Agricultural and Forest Meteorology 149:3-4, pp. 443–452.

Tadesse, et al., 2015. Evaluating a satellite-based seasonal evapotranspiration product and identifying its relationship with other satellite-derived products and crop yield: A case study for Ethiopia. International Journal of Applied Earth Observation and Geoinformation 40 (2015) 39–54

US-NOAA News. (2001). Drought: The Creeping Disaster. Retrieved April 25, 2017 from http://www.noaanews.noaa.gov/stories/s600b.htm.

Wilhite, Donald A., 2011. Quantification of Agricultural Drought for Effective Drought Mitigation and Preparedness: Key Issues and Challenges. Drought Mitigation Center Faculty Publications. Paper 82. Retrieved May 7, 2017 from http://digitalcommons.unl.edu /droughtfacpub/82

Wilhite, D.A. and Glantz, M.H., 1985. Understanding the drought phenomenon: The role of definitions. Water International, 10(3): pp. 111-120.

Yumul, Graciano P. Jr., et al. 2010. The 2009-2010 El Niño Southern Oscillation in the Context of Climate Uncertainty: The Philippine Setting. Philippine Journal of Science 139 (1): 119-126, June 2010 ISSN 0031 - 7683.

Zhang, Yongqiang, et al. 2004. Effect of soil water deficit on evapotranspiration, crop yield, and water use efficiency in the North China Plain. Agricultural Water Management 64 (2004) 107–122