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ORIGINAL ARTICLE

Application of Remote Sensing on El Niño Extreme Effect in Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI)

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Abstract

The years 1997/1998 and 2015/2016 saw the worst El Niño occurrence in human history. The occurrence of El Niño causes extreme temperature events which are higher than usual, drought and prolonged drought. The incident caused a decline in the ability of plants in carrying out the process of photosynthesis. This causes the carbon dioxide content to be higher than normal. Studies on the effects of El Niño and its degree of strength are still under-studied especially by researchers in the tropics. This study uses remote sensing technology that can provide spatial information. The first step of remote sensing data needs to go through the pre-process before building the NDVI (Normalized Difference Vegetation Index) and Normalized Difference Water Index (NDWI) maps. Next this study will identify the relationship between Oceanic Nino Index (ONI) with Application Remote Sensing in The Study Of El Niño Extreme Effect 1997/1998 and 2015/2016 On Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI)NDWI and NDWI landscape indices. Next will make a comparison, statistical and spatial information space between NDWI and NDVI for each year 1997/1998 and 2015/2016. This study is very important in providing spatial information to those responsible in preparing measures in reducing the impact of El Niño.

Keywords: El Nino, Normalized Difference Vegetation Index, Normalized Difference Water Index, Remote Sensing

Introduction

In Malaysia, this El Niño incident significantly causes a decrease in the amount of rainfall to increase the temperature (Tanggang et al., 2018). This causes prolonged drought and drought which causes water content in plants and the environment to decrease. This study chose to use NDVI and NDWI. This NDVI is the most important spectral indices because it is closely related to the active rate of photosynthesis process that is through chlorophyll content in leave to absorb light energy. NDVI and NDWI are important indices in lowering the temperature due to the effects of urban heat islands. The degree of impact of urban heat islands will increase during El Nino.

This matter is important to study the impact of El Niño events on NDVI and NDWI in understanding the effects of El Niño especially in urban areas. This study investigates about the relationship between extreme climates due to the strong 1997/1998 and 2015/2016 El Niño on NDVI and NDWI.

In the Amazon, Brazil reported an increase in the amount of carbon dioxide in El Niño in 2015/2016 (Betts et al., 2016) due to a decrease in the rate of photosynthesis (Gloor et al., 2018; Liu et al., 2017). In addition, Sangwangsri et al., (2017) also found that the occurrence of El Niño 2010 and 2015/2016 caused the rate of grow primary productivity (GPP) and evapotranspiration decreased due to the lack of total rainfall during El Niño in Thailand. For the Sarawak Borneo area, Itoh et al., (2012) and Nakagawa et al., (2000) found that the value of El Niño causes the effect on plants to be higher on small trees than on large trees.

However, Yang et al (2018) reported that photosynthesis rate increased during El Niño in 2015/2016. The following contradicts the results of studies on the effect of ENSO on photosynthesis. Addition, investigations into the effects of extreme climate events on CO2 and seasonal exchange of trees in urban plants are still rare, although they have high potential to disrupt crop productivity through phenological disturbances (Kaewthongrach, et al. 2020). Connecting phenology and climate information across space scales is need to lay the groundwork for predicting sensitivity, adaptive capacity, and vulnerability of species as well as ecosystems to future climate change (Enquist et al., 2014; Vose et al., 2012). The information on NDVI level functions can also provide insights for urban forest management (Brearley et al., 2016).

Materials and Methods

The Remote Sensing technique has been used in this study. In general, Figure 1 shows the flow chart of each step carried out to achieve the objectives of the study.

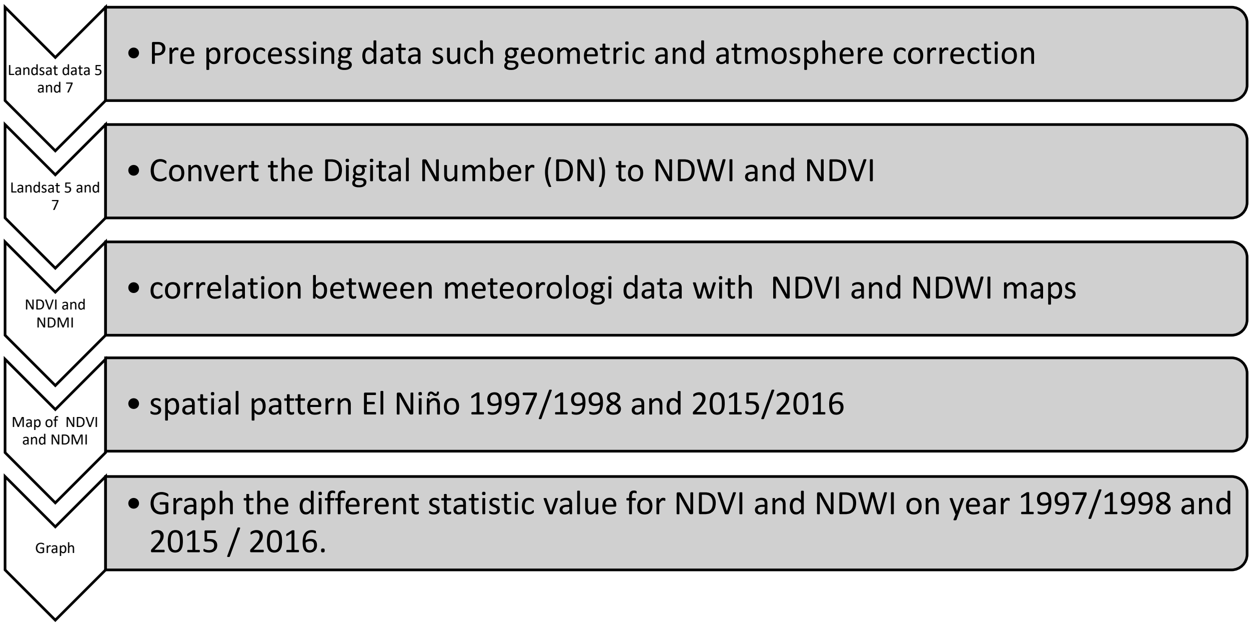


Figure 1: The flow chart of each step carried out to achieve the objectives of the study

Every Landsat data has to go through pre-process processes such as geometry and atmosphere. Next is the process of converting the value of DN to NDWI and NDVI. The Calculations and formulas to convert DN to NDWI and NDVI was based on research papers (Ricky and Oliver, 2019). After the NDWI and NDVI maps were successfully generated. Correlation analysis should be made between NDWI and NDVI with ONI. The next step is to compare the spatial patterns for each NDWI and NDVI map for the 1997/1998 and 2015/2016 El Niño years.

The next step is to make a comparison between the statistical values of mean, maximal and minimum of each NDWI and NDVI maps for 1997/1998 and 2015/2016. To facilitate understanding of the comparison between the events of El Niño 1997/1998 and 2015/2016 statistical data will be presented in graph form.

Oceanic Niño Indeks (ONI)

The ONI is well establised to identify events of El Niño and La Niña (Huang et al., 2016). The ONI index shows the development and intensity of El Niño or La Niña events in the Pacific Ocean. ONI is a three-month Sea Temperature (SST) anomaly in Niño region 3.4 5 ° N - 5 ° S, 120 ° - 170 ° W (see table 1).

Table 1: Classification of ENSO Events

SST anomaly (ONI)	Category ENSO
ONI ≥ 2.0	Very strong El Niño
1.5 to 1.9	Strong El Niño
1.0 to 1.4	Moderate El Niño
0.5 to 0.9	Weak El Niño
-0.5 to 0.5	Neutral
ONI ≥ -2.0	Very strong La Niña
-1.5 to -1.9	Strong La Niña
-1.0 to -1.4	Moderate La Niña
-0.5 to -0.9	Weak La Niña

The occurrence of El Niño when the ONI value is for three months the average SST anomaly at a positive 0.5-degree Celsius and above and the occurrence of La Niña is when the negative value 0.5 degrees Celsius anomaly and below (NOAA - Climate Prediction Center, 2020) (see table 2).

Table 2: The value of ONI for Year 1997/1998 and 2015/2016 used in this study

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1997	-0.5	-0.4	-0.1	0.3	0.8	1.2	1.6	1.9	2.1	2.3	2.4	2.4
1998	2.2	1.9	1.4	1.0	0.5	-0.1	-0.8	-1.1	-1.3	-1.4	-1.5	-1.6
2015	0.6	0.6	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.5	2.6
2016	2.5	2.2	1.7	1.0	0.5	0.0	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6

Landsat 5 Thematic Mapper (TM) and 7 Enhanced Thematic Mapper (ETM)

Table 3 shows the data used in this study to achieve the objectives. Data selection is only against Landsat data for which there is no cloud coverage. This is because passive remote sensing sensors are unable to penetrate the cloud surface. The selection of data also only involves the year of El Niño which is 1997/1998 and 2015/2016.

Table 3: The Landsat dataset was applied for this study

Sensor	Date Data Acquisition	Data Resolution (Meters)
Landsat 5 TM	18 May 1997	100 resolution resample to 30
Landsat 5 TM	19 June 1997	100 resolution resample to 30
Landsat 5 TM	19 April 1998	100 resolution resample to 30
Landsat 7 ETM	15 June 2015	100 resolution resample to 30
Landsat 7 ETM	11 October 2015	100 resolution resample to 30
Landsat 7 ETM	1 April 2016	100 resolution resample to 30

Landscape Indices

The selected parameter to assess urban vegetation and moisture vegetation at urban areas (see table 4).

Table 4: The selected landscape indices for this study.

Parameter	**Index Name**	**Reference**
Health vegetation	Normalized Difference Vegetation Index	Ogashawara and Bastos, 2012
Plant water content	Normalized Difference Moisture Index	Gao et al. (1996)

Normalised Difference Vegetation Index (NDVI)

NDVI was computed as a proportion between the red wavelength and near-infrared (wavelength values) as mentioned at formula below.

$$NDVI = \frac{NIR - R}{NIR + R}$$

The normalized vegetation index (NDVI) is one of the most used spectral indices because it is closely related to the amount of photosynthetically active radiation intercepted by vegetation, and the amount of green biomass and chlorophyll content in leaves (Tucker et al., 1985; Baret, 1991; Gamon et al., 1995; Huete et al., 1997). This spectral index may provide valuable information on the temporal dynamics of photosynthetic activity and primary productivity (Gamon et al., 1995; Muraoka et al., 2013) (see table 5).

Table 5: The selection band for calculated NDVI

Sensor	Selection band for calculated NDVI
Landsat 5,7,	(Band 4 – Band 3) / (Band 4 + Band 3).

NDWI

The Normalized Water Difference Index (NDWI) Gulacsi and Kovacs (2015) is an index of Near Infrared Channels (NIR) and Shortwave (SWIR) as mentioned at formula below.

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR}$$

SWIR reflection reflects change in the air content of plants and the spongy mesophilic structure in the canopy of plants. The reflection of NIR is influenced by the internal structure of the leaf and the content of the dry matter of the leaf or there is a water content. Combination of NIR with SWIR variation caused by leaves the internal structure and content of the dry matter of the leaves, increase the accuracy in the intake of plants air content (Ceccato et al. 2001).

The amount of air present in the inner leaf structure largely spectrum reflections appear in the SWIR interval of the electromagnetic spectrum. Its use for drought monitoring and early warning has been used in various studies. (Gu et al., 2007; Ceccato et al., 2002). It is calculated using near infrared (NIR) and short infrared wave reflection (SWIR) which makes it sensitive to changes in air content and in mesophile soppy canopy of plants (Gao, 1996; Ceccato et al., 2001).

Table 6 shows the selection band for calculated NDMI for Landsat 4 and 7. Band 4 at Landsat 4 and 7 represent NIR and band 5 represent SWIR wavelength.

Table 6: The selection band for calculated NDWI

Sensor	Selection band for calculated NDWI
Landsat 5,7,	(Band 4 – Band 5) / (Band 4 + Band 5).

Study Area

The climate in Kuching is influenced by MJO, ENSO, IOD (Hua et al., 2013) and Monsoon season (Dindang et al., 2013; Yik et al., 2015). In recent years, ENSO phenomena, climate change, and several incidents of heavy rainfall have been reported in Borneo Malaysia including in the study area, namely Kuching (Zulfaqar et al., 2017). In 2015, the floods left many low-lying areas in Kuching, Sarawak (Zulfaqar et al., 2017).

On the other hand, 2009 was also recognized as the last year for Sarawak when two major rainfall events caused severe floods covering the whole of Sarawak including Kuching (Hamdan et al., 2010). This phenomenon has raised concerns to encourage more research on meteorological data flow analysis to examine whether these changes are statistically significant or significant (Zulfaqar et al., 2017). Iin addition, there is still a lack of previous studies examining the effects of El Niño in the tropics specifically the Kuching city area especially on temperature. Figure 2 shows the location of study areas in Sarawak, Malaysia.

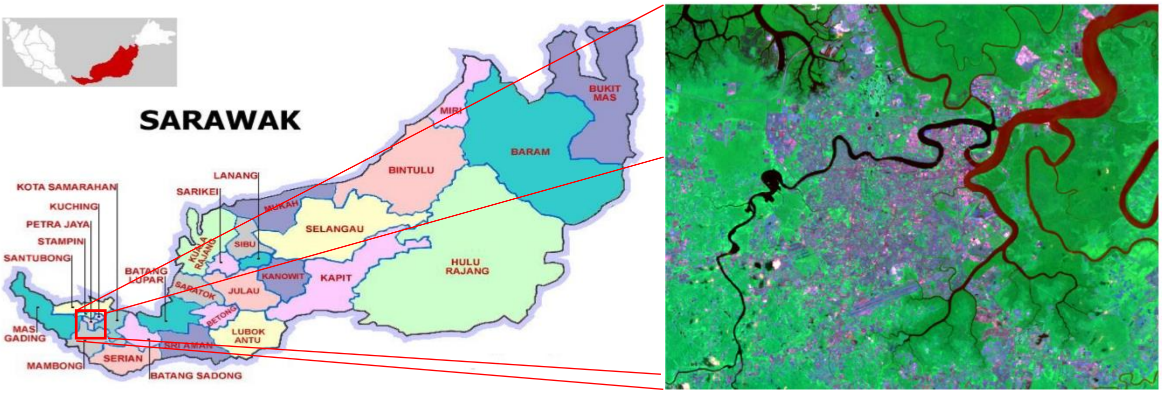


Figure 2: The location of study areas in Sarawak, Malaysia.

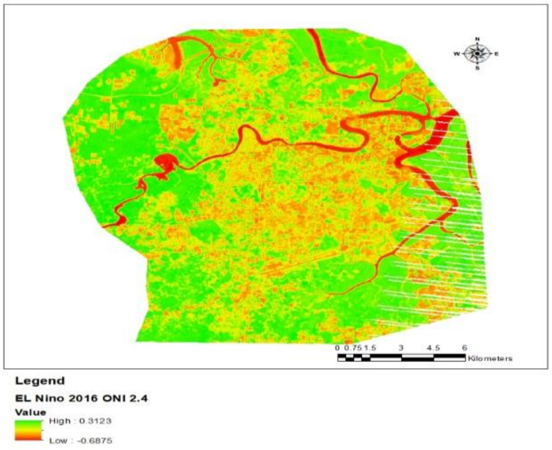
Result and Discussion

Based on this study, Figure 3 shows that there is a change in the pattern of space between El Niño especially the maximum and minimum values. The table describes the NDVI column changes between 1997/1998 and 2015/2016 El Niño.

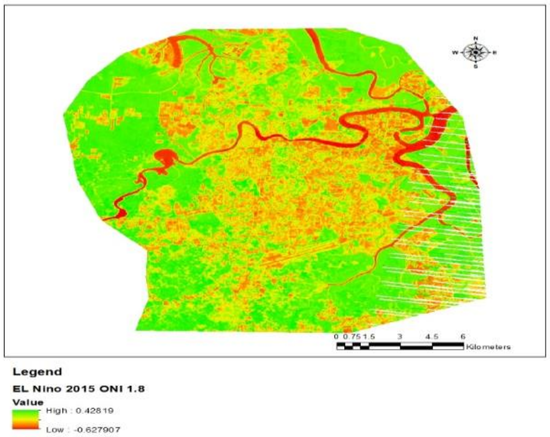
Table 7 shows the difference of El Niño 2015/2016 and El Niño 1997/1998 where the mean NDVI value for El Niño 1997/1998 higher than that of El Niño 2015/2016. In addition, the maximum NDVI value for El Niño 1997/1998 is also higher compared to the 2015/2016 El Niño NDVI value. Besides that, the minimum NDVI value for El Niño 1997/1998 higher than value El Niño 2015/2016.

Suepa et al., (2016) stated the El Niño could result in a replacement of high-quality vegetation with low quality forest which likely to lead to a significant biodiversity loss. Besides that, Stefan et al., (2009) found that the occurrence of ENSO represented by SOI found that NDVI value decreased during the El Niño event. ENSO incidents in 1997 and 1998 confirmed their forecast results. El Niño which causes higher than normal temperatures cause drought and drought in Indonesia compared to during the La Niña incident.

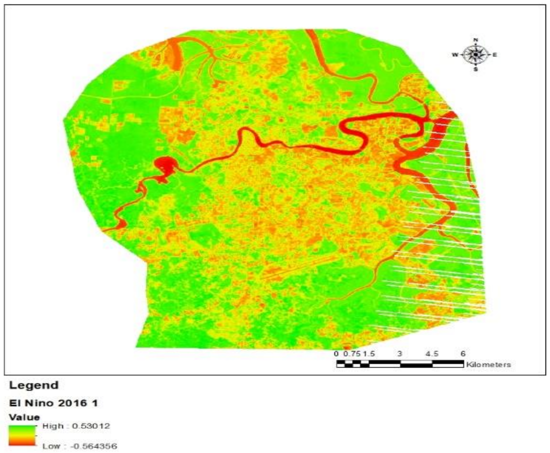
The results of their study are very important in the agricultural sector where through the use of remote sensing they managed to identify areas that are severely affected by ENSO. The results of this study also allow local governments to prepare for the upcoming El Niño. The above studies use AVHRR, MODIS and SOI. Through this study we get the effectiveness and capability of MODIS in studying the relationship with ONI.



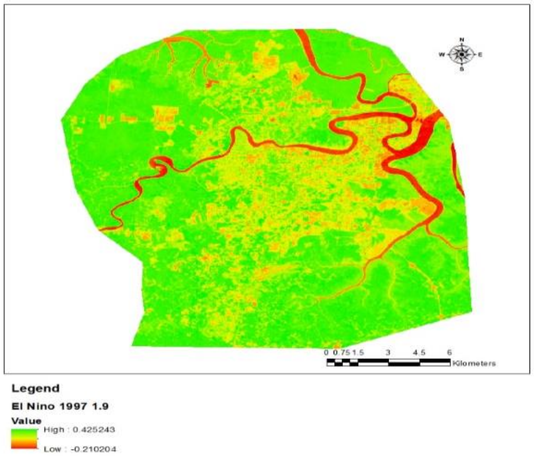
a) El Niño 2016 with value ONI 2.4



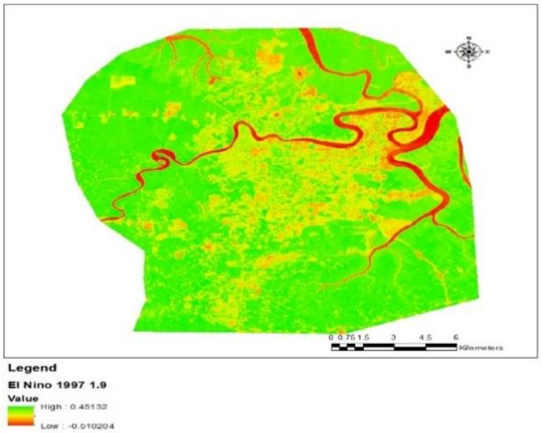
b) El Niño 2015 with value ONI 1.8



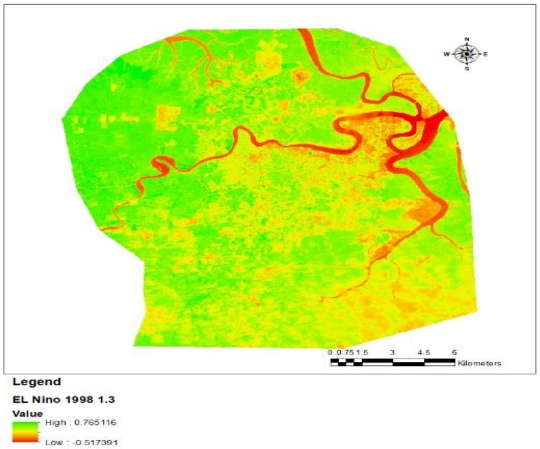
c) El Niño 2016 with value ONI 1



d) El Niño 1997 with value ONI 1.9



e) El Niño 1997 with value ONI 1.9



f) El Niño 1997 with value ONI 1.3

Figure 3: The spatial pattern for NDVI between El Niño 2015/2016 (Figure a, b, c) and El Niño 1997/1998 (Figure d, e, f)

A study conducted by Subhanil et al., (2019) on the effect of monsoon on spectral indices such as NDVI, Normalized difference water index, normalized built up index and normalized multiband drought index based on four different seasons namely pre monsoon, monsoon, post monsoon and winter using Landsat and MODIS satellite data. Their study found that the maximum value, and mean for NDVI was higher during the monsoon and post monsoon seasons compared to the winter and pre monsoon. This explains the maximum NDVI value and high mean during the La Niña incident. The monsoon season and post monsoon season are linked to bringing moisture to the environment.

Based on Table 7, 8 and Figure 4 shows that there is a change in the pattern of space between El Niño especially the maximum and minimum values. The table describes the NDWI column changes between 1997/1998 and 2015/2016 El Niño.

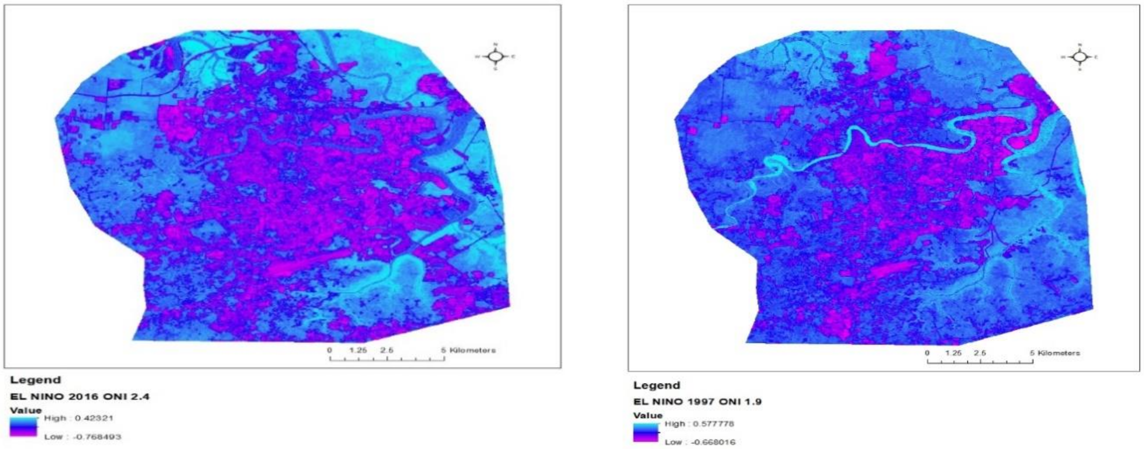
Based on the table above (Table 8) shows the difference of El Niño 2015/2016 and El Niño 1997/1998 where the mean NDWI value mean depends ONI value. For example, value mean NDWI 1997/1998 where value ONI 1.3 higher that El Niño 2015/2016 when ONI 1.8. The value the maximum NDWI value for El Niño 1997/1998 is also higher compared to the 2015/2016 El Niño NDWI value when the value ONI 1.9. this means that the ONI value affects the NDMI value. The NDWI value increases if the ONI value decreases. Gulacsi and Kovacs (2015) has built the drought category of NDWI as shown in the Table 9.

Table 7: NDVI Value between 1997/1998 and 2015/2016 El Niño

Statistic Value	ONI Value	El Niño 2015/2016	ONI Value	El Niño 1997/1998
Maximum	2.4	0.3123	1.9	0.45132
Minimum		-0.6875		-0.5102
Mean		0.2981		0.41233
Maximum	1.8	0.42819	1.3	0.7651
Minimum		-0.6279		-0.5173
Mean		0.3134		0.6619
Maximum	1	0.53012	1.9	0.4252
Minimum		-0.5643		-0.2110
Mean		0.40891		0.41032

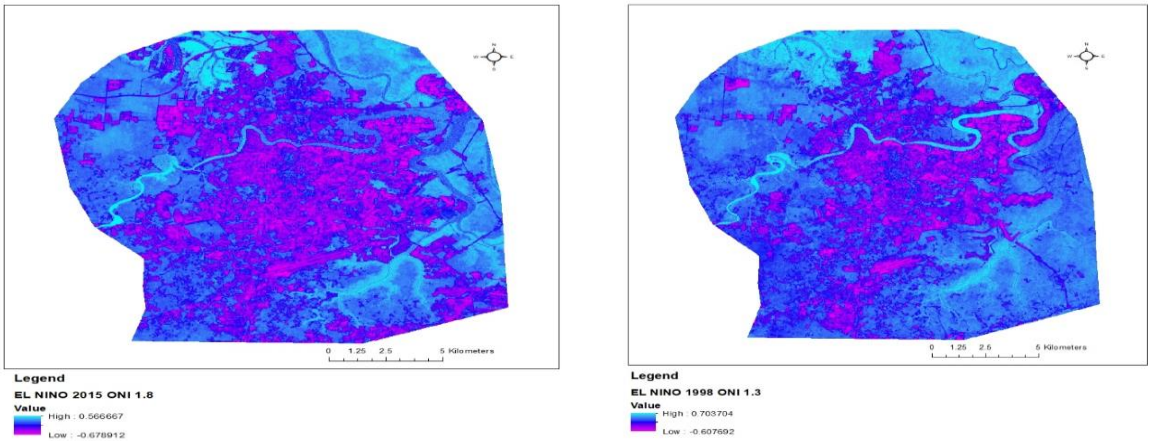
Table 8: NDWI Value between 1997/1998 and 2015/2016 El Niño.

Statistic Value	ONI Value	El Niño 2015/2016	ONI Value	El Niño 1997/1998
Maximum	2.4	0.4231	1.9	0.5037
Minimum		-0.7684		-0.6076
Mean		0.40132		0.5012
Maximum	1.8	0.5666	1.3	0.7555
Minimum		-0.6789		-0.6306
Mean		0.46156		0.71234
Maximum	1	0.6132	1.9	0.5177
Minimum		-0.568		-0.6668
Mean		0.4789		0.5100



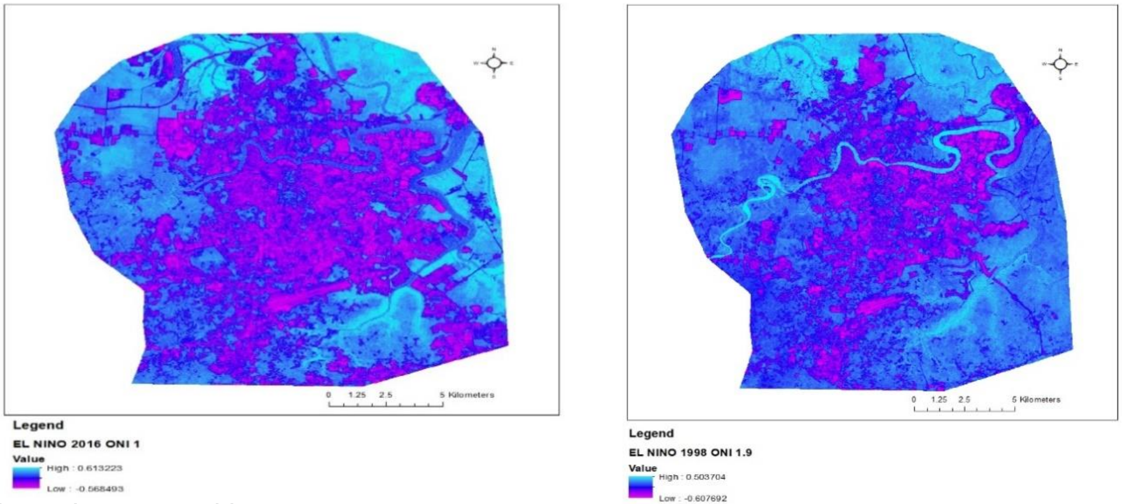
a) El Niño 2016 with value ONI 2.4

d) El Niño 1997 with value ONI 1.9



b) El Niño 2015 with value ONI 1.8

e) El Niño 1998 with value ONI 1.3



c) El Niño 2016 with value ONI 1

f) El Niño 1998 with value ONI 1.9

Figure 4: The spatial pattern for NDWI between El Niño 2015/2016 (a, b, c) and El Niño 1997/1998 (d, e, f)

Table 9: The drought category of NDWI

Category	Values
Very high moisture content	≥ 0.7
High moisture content	0.6 - 0.7
Moderate moisture content	0.5 - 0.6
Low moisture content	0.4 – 0.5
Weak drought	0.3 – 0.4
Moderate draught	0.2 – 03
Strong draught	0.1-0.2
Very strong draught	≥ 0

Table 9 show the drought category NDWI develop by Gulacsi and Kovacs (2015). The value higher 0.7 denoted very high moisture content and value below 0 is very strong draught. Referring to table 9, it is found that the effect of El Niño 2015/2016 is worse where the mean value of NDWI is 0.4 -0.5 which is low water contents. For El Niño 1997/1998 it was found that the mean value of NDWI is 0.5-0.6 which is moderate moisture water content. Luisa et al., (2018) monitor draught using NDWI in West Java during El Niño 2015 and found the value of NDWI decreased significantly start from May-June 2015 and increased in November 2015.

This is due to the increase in the value of ONI which causes an increase in temperature and at the same time causes dryness and heat in May-June 2015 which can be referred to graph 3. The results of this study are also supported by Farras et al., (2017) who found that the occurrence of La Niña brings rainfall and El Niño brings dryness and higher temperature than usual. This explains the reason for the devaluation of the NDWI. Studies on the effect of ENSO on NDWI are still few compared to NDVI. However, the results are almost the same as the effect of ENSO on NDVI.

Conclusion

The events of El Niño in 1997/1998 and 2015/2016 have an impact on plant health and its ability to carry out the process of photosynthesis which is an important natural process in balancing the carbon dioxide cycle. The results of this study have the effect of El Niño in 2015/2016 worse than the effect of El Niño in 1997/1998 due to land use factors. The increase in urban areas resulted in the loss of green areas resulting in higher temperatures compared to 1997/1998 effects of urban heat islands.

However, the result of these findings is that the occurrence of El Niño causes the rate of photosynthesis process to decrease which is represented by NDVI values. This NDVI value is negatively related to ONI. The NDVI value will decrease if the ONI value increases. This means that an increase in the degree of El Niño will cause a decrease in the process of photosynthesis.

Acknowledgement

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