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Climate Anomalies of Maize Drought Level based on Land Water Balance in Gorontalo Province, Indonesia

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ABSTRACT

Background: The complexity of the distribution patterns of drought and soil water balance across various regions raises questions about how the mechanism of drought events responds to climate anomalies. The research aims to determine the climate anomaly pattern of maize drought levels based on land water balance with FAO Penman Monteith evapotranspiration value estimates in Gorontalo district, Indonesia. This research was carried out from April to August 2020.

Methods: The research location was in Limboto subdistrict, Gorontalo Province, Indonesia. The material in this research is climate data from 1997 to 2016 (20 years) including rainfall, solar radiation, maximum and minimum air temperature, exposure time, air humidity and wind speed. The tools in this research are sample rings, Belgi drills, GPS, documentation tools. The method used is the drought index analysis method and the water adequacy index based on the FAO Penman Monteith evapotranspiration method.

Result: El Nino and La Nina climate anomaly patterns occur every 5 to 7 year recurring period. The highest level of drought with strong drought status occurred during the El Nino anomaly in 1997-1998 for 8 months and this triggered a decrease in harvested area and corn production with a coefficient of reduction in vulnerable production category. La Niña climate anomaly years 1999 and 2007 had an impact on low accumulation potential of water loss with highest level of drought weak status and this triggered an increase in harvested area and corn production with a coefficient of reduction in very resistant production category.

Key words: Maize, Climate anomalies, Drought, Land water balance.

INTRODUCTION

Climate anomalies and meteorological disasters have become the greatest challenges for humanity. The increasing frequency of extreme weather and climate events has exacerbated damage worldwide in recent years. The United Nations reports that between 1998 and 2017, disaster-affected countries experienced economic losses with 77% of the total losses caused by climate disasters. (Wang *et al.,* 2022; Ao *et al.* (2020); González-Orenga *et al.* (2022); Pembengo *et al.* (2023) explains that climate change is a global problem through increasing the earth's surface temperature, exacerbating the intensity of extreme weather and increasing the frequency of floods and droughts. Climate anomalies occur for several reasons, including the ENSO (El-Niño Southern Oscillation) phenomenon, which is associated with sea surface temperature anomalies conditions in Pacific ocean and IOD (Indian Ocean Dipole Mode) event which is associated with sea surface temperature anomalies in the Indian Ocean. These two main factors are the dominant causes of climate anomalies in Indonesia (Pembengo and Rahim, 2020).

Drought is the biggest threat to food crops in almost every region of the world. By 2030, around 40% of the world's population will suffer from water scarcity and 700 million people will be displaced due to this risk (Molla *et al.,* 2023; Wang *et al.,* 2015). Direct impact of climate change is an increase in temperature which increases rate of water evaporation and triggers risk of prolonged drought (Pembengo and Dude, 2024; Shukla *et al.,* 2021). Climate anomalies have different impacts on different types of drought through their influence on the mechanisms by which rainfall deficiencies become hydrological droughts (Hosseinzadehtalaei *et al.,* 2023). The complexity of the distribution patterns of drought and land water balance across various regions raises questions about how the mechanism of drought events responds to climate anomalies.

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Land water balance has a response to climate anomalies in evaluating changes in groundwater. Climate anomalies will cause different hydrological cycles, with changes in rainfall, evapotranspiration, the amount and timing of runoff. The impact on water balance patterns, especially quantity and quality, will influence changes in soil's ability to store water, high of groundwater levels and soil moisture status (Magyar *et al.,* 2023; Muluneh, 2020).

Maize (*Zea mays* L.) is the world's most important food crop, ranking third after rice and wheat. Its versatility as a food source, feed source and fuel source makes it a plant that can make a major contribution to a country's food security and food self-sufficiency. (Dehghanisanij *et al.,* 2020; Greaves and Wang, 2017). Maize growth is more sensitive to drought stress in the early stages of development and grain filling phase (Wei *et al.,* 2019). The impact of drought on maize growth varies with the level and timing of stress severity. The most critical period of water requirements is between 2-3 weeks before silking (Song *et al.,* 2010). Drought stress reduces the rate of evapotranspiration and maize biomass accumulation during summer.

Evapotranspiration in agricultural ecosystems is an important component for optimizing agricultural management and increasing crop water use efficiency (Gao *et al.,* 2020). Among the various types of evapotranspiration models, the FAO Penman-Monteith model is considered as a direct and commonly applied method due to its physical mechanisms that well describe the water transport processes and heat dynamics (Cui *et al.,* 2023; Ippolito *et al.,* 2024). Estimating precise evapotranspiration values in maize fields is still a challenge because there are many factors that influence soil-plant atmosphere interactions, for example climate type, soil type, soil processing techniques and application of cropping patterns (Liu *et al.,* 2024). Maize fields often show strong spatial and temporal variations due to changes in tillage practices, cropping patterns and maize plant density. In dry years evapotranspiration in maize fields is mainly influenced by net radiation, soil water content and vapor pressure deficit. In normal years it tends to be influenced by net radiation, leaf area index and vapor pressure deficit. This shows that drought can increase the sensitivity of maize evapotranspiration rates to water availability and reduce sensitivity to patterns of changes in available energy in aerodynamic conditions and vegetation cover (Zheng *et al.,* 2024).

Based on the background above, the research aims determine the climate anomaly pattern of maize drought levels based on land water balance with FAO Penman Monteith evapotranspiration value estimates in Gorontalo district, Indonesia.

MATERIALS AND METHODS

This research was carried out from April to August 2020. The research location was in Limboto subdistrict, Gorontalo Province, Indonesia. The material in this research is climate data from 1997 to 2016 (20 years) including data on rainfall, solar radiation, maximum and minimum air temperature, duration of exposure, air humidity and wind speed. The tools in this research are sample rings, Belgi drills, GPS, documentation tools.

The method used is the drought index analysis method and the water adequacy index based on the FAO Penman Monteith evapotranspiration method. The work steps are :

1. Recapitulate rainfall data.
2. Calculate standard evapotranspiration (ETo) and potential evapotranspiration (ETp) using the FAO Penman-Monteith method.

$$ETo = \frac{0{,}408\Delta(Rn\text{-}G)+Y(900/(T*273)U2(es\text{-}ea)}{\Delta+Y(1+0{,}34U2)} \quad ...(1)$$

3. Calculate the difference in rainfall and potential evapotranspiration values.
4. Calculate accumulated potential water loss (APWL) value which is calculated from the total accumulated rainfall value minus potential evapotranspiration which is negative.
5. Calculate value of soil water content (SWC) based on the equation;

$$SWC = FCexp^{(APWL/FC)} \quad ...(2)$$

If there is no APWL value in that month, then:

SWC = SWC previous month + (Rainfall-ETp)

Information :

SWC = Soil water content.

FC = Field capacity.

APWL = Accumulation of potential water loss.

If value SWC reach field capacity, so SWC = FC

6. Calculate the value of changes in soil water content (dSWC) with the equation:

$$dSWC = SWC_i – SWC_i \quad ...(3)$$

Information :

dSWC = The difference in soil water content during one period with the previous period. A positive soil water content value indicates an increase in soil water content (rainy season), adding stops when dSWC = 0. On the other hand, if the rainfall is smaller ETp or dSWC negative indicates reduction SWC or all rainfall and some SWC will be evapotranspired.

7. Calculate actual evapotranspiration value (ETa) based on the following equation;

$$\text{If Rainfall} > ETp \text{ so } ETa = ETp \quad ...(4)$$

$$\text{If rainfall} < ETp \text{ so } ETa = \text{Rainfall} + dSWC \quad ...(5)$$

Information:

Value dSWC is an absolute value, meaning that negative signs are ignored in calculations. When Rainfall < ETp so ETa will be lower than ETP value.

8. Calculate the water deficit and surplus values.

$$D = ETp - ETa \quad ...(6)$$

$$S = Rainfall - ETp - SWC \quad ...(7)$$

Information:
D = Defisit.
S = Surplus.
ETA = Actual evapotranspiration.

9. Calculate the drought index (Ia) and the level of the drought index.

$$Ia = (D/ETP) \times 100\% \quad \text{...(8)}$$

Information:
Ia = Drought index.

The distribution of drought index levels can be explained in (Table 1).

10. Calculate value of coefficient of reduction in crop production (ky)

$$ky = (1\text{-}ETa/ETp) \times 100\%. \quad \text{...(9)}$$

11. Classify according to category (Tabel 2).

RESULTS AND DISCUSSION

Drought index

Based on Table 3, level of drought during the strong El Nino climate anomaly in 1997-1998, 2002-2003 and 2015-2016 had strong (S) to moderate (M) drought levels with an average number of months of 9, 7 and 13 months. The level of drought in the year of the moderate El Nino climate anomaly in 2009-2010 had a moderate (M) to strong (S) level of drought with an average number of months of 6 months. The occurrence of drought levels in strong and moderate Elnino years is dominated by moderate (M) to strong (S) drought levels. This has the potential to influence the pattern and timing of maize planting, thereby potentially affecting maize productivity. On the other hand, in a normal year, the drought level is dominated by a weak level (W). The occurrence of climate anomalies since more than 100 years ago shows that the average duration of El-Nino events is around 8.5 months with a range of 4 - 12 months, while La Nina months range from 5 - 15 months. The El-Nino climate anomaly causes changes in the delay in planting time which will impact the following year's planting season. El-Nino 1997 shifted the 1997-1998 planting time by 2-3 months (6-9 days) which also significantly affected subsequent planting patterns Irawan (2006a); Garcia *et al.* (2009) stated that there are main impacts of climate variability, especially during the transition period, in the form of soil water content with different conditions, erratic

Table 1: Classification of drought index levels.

Drought Index (%)	Drought level
< 16.77	Weak (W)
16.77 – 33.33	Moderate (M)
> 33.33	Strong (S)

Table 2: Classification of coefficient of reduction in crop production.

Index coefficient of reduction in crop production	Category
0.50 - 1.00	Very vulnerable
0.30 - 0.50	Vulnerable
0.15 - 0.30	Moderate
0.05 - 0.15	Resistant
0.00 - 0.05	Very resistant

Source: (Pramudia, 2008)

Table 3: Drought Levels in Gorontalo Regency from 1997 to 2016 (20 Years).

Year	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
1997 (strong El Nino)				W		M	M	S	S	S		S
1998 (strong El Nino)	S	S	S	S				W	W			
1999 (strong La Nina)		W						W	W			W
2000 (Normal)			W	W	W		W	W	W			W
2001 (Normal)							W	M	M	M		
2002 (strong El Nino)		W	W			W	M	S	S	S	W	W
2003 (strong El Nino)	S	S				W	W	W	S	W	W	
2004 (Normal)		W	W			W	W	S	W	W	M	W
2005 (Normal)	S	W	W	W		M		W	W		W	
2006 (Normal)			W		W		W	S	S	S		
2007 (Mod La Nina)		W	W				W	W	W	W	W	
2008 (Mod La Nina)		W							W			
2009 (Mod El Nino)							W	M	S	S		S
2010 (Mod El Nino)	M	M	W								W	
2011 (Normal)	W						M	W	W		W	
2012 (Normal)	W	W	W					W	W	W		W
2013 (Normal)			W						W		W	
2014 Normal)		M	W				W	W	M	M		
2015 (strong El Nino)	W	M	S	M			S	S	S	S		S
2016 (strong El Nino)	M	S	S	M				W	M			

Information: W = Weak; M = Moderate; S = Strong.

soil temperatures that trigger the size of evaporation and transpiration, which have the potential to disrupt the productivity of maize plants. Hassanli *et al.* (2009) stated that implementing an appropriate irrigation schedule, especially in sensitive and critical maize development phases, is necessary for efficient water use.

Based on Table 3, pattern of repeated occurrence of drought climate anomalies or El Nino phenomenon ranges from 5 to 6 years, namely 1997-1998, 2002-2003, 2009-2010 and 2015-2016. The frequency of El Nino events tends to increase with longer duration, greater levels of climate anomalies and shorter event cycles. This climate anomaly causes a decrease in rainfall and the availability of irrigation water, which in turn has implications for a decrease in food production of 3.06 per cent for each El Nino event. On the other hand, La Nina events tend to be followed by increased rainfall and stimulate an increase in food production of 1.08 percent. The impact of El Nino year on corn is a decrease in production of 11.93% and in La Nina year there was an increase in production of 3.92% (Table 4). The decline in food production due to the El Nino climate anomaly and the increase in food production due to La Nina was highest in maize production (Irawan, 2006a). This shows that maize production is most sensitive to climate anomaly events.

Based on Table 5, from 1996 to 2001 the harvested area and corn production were still very low compared to 2002 to 2016. This was because from 2002 to 2014 Gorontalo area became an autonomous provincial region with the main Corn Agropolitan program. This program was able to encourage an increase in harvested area and corn production from 2002 to 2014, but there was a decrease in production in the strong and moderate El Nino climate anomaly years, namely 1997-1998, 2002-2003, 2009-2010 and 2015-2016. This is in accordance with coefficient of reduction in corn production which is categorized as vulnerable to moderate to a decline in production due to El Nino climate anomaly. This is because during El Nino climate anomaly, such as in 1997, there was a water deficit for 6 months from June to November (Table 6). According to Lesilolo *et al.* (2024) food plants with relatively shallow roots are plants most sensitive to

Table 4: Impact of climate anomalies that occurred during 1968-2000 on food production by commodity type (%).

Climatic conditions	Types of food commodities					
	All commodities	Rice Field	Corn	Cassava	Peanuts	Soybean
Quantity (thousand tons)	- 1794.8	- 781.5	- 601.2	- 182.3	- 94.2	- 52.3
El NinoLa Nina	521.0	124.9	158.9	166.6	32.7	15.2
Percentage (%)	- 3.06	- 2.43	- 11.9	- 1.28	- 4.74	- 5.10
El NinoLa Nina	1.08	0.61	33.92	1.16	1.44	1.73

Source: (Irawan, 2006b).

Table 5: Harvested area, production and coefficient of reduction in corn production in 1997-2016, Gorontalo Province, Indonesia.

Year	Harvested area (ha)	Production (ton/year)	Coefficient of reduction in corn production (ky)	Category
1997 (strong El Nino)	14614	30120	0.33	Vulnerable
1998 (strong El Nino)	14200	35500	0.25	Moderate
1999 (strong La Nina)	40695	90288	0.00	Very resistant
2000 (Normal)	34492	96527	0.01	Very resistant
2001 (Normal)	27193	94469	0.05	Resistant
2002 (strong El Nino)	45718	130251	0.31	Vulnerable
2003 (strong El Nino)	58716	123998	0.28	Moderate
2004 (Normal)	75529	251214	0.09	Resistant
2005 (Normal)	107752	400045	0.04	Very resistant
2006 (Normal)	109792	416222	0.13	Resistant
2007 (La Nina Mod)	119027	572785	0.03	Very resistant
2008 (La Nina Mod)	156436	753598	0.00	Very resistant
2009 (El Nino Mod)	124798	569110	0.17	Moderate
2010 (El Nino Mod)	143833	549168	0.16	Moderate
2011 (Normal)	135754	605781	0.03	Very resistant
2012 (Normal)	135543	644754	0.01	Very resistant
2013 (Normal)	140423	669095	0.00	Very rpesistant
2014 Normal)	148816	719787	0.07	Resistant
2015 (strong El Nino)	129131	543512	0.31	Vulnerable
2016 (strong El Nino)	110025	520200	0.26	Moderate

Table 6: Corn of land water balance in 1997 El Nino climate anomaly.

Month	P (mm)	ETP (mm)	kc Corn	ETc	P-ETc	APWL	Field capacity (mm)	Soil water content (SWC) (mm)	dSWC	ETa	Deficit	Surplus
Jan	188	36.68	1.05	38.52	149		381	381.00	31.00	38.52	0.00	120
Feb	124	121.48	0.95	115.40	9		381	381.00	0.00	115.40	0.00	3
Mar	298	128.47	0.6	77.08	221		381	381.00	0.00	77.08	0.00	170
Apr	97	67.64	1.05	71.02	26		381	381.00	0.00	71.02	0.00	29
May	112	34.85	0.95	33.11	79		381	381.00	0.00	33.11	0.00	77
Jun	3	92.90	0.6	55.74	-53	-53	381	306.67	-74.33	77.33	15.58	0
Jul	58	112.20	1.05	117.81	-60	-113	381	271.73	-34.94	92.94	19.26	0
Aug	0	71.89	0.95	68.30	-68	-181	381	234.32	-37.40	37.40	34.48	0
Sep	1	44.17	0.6	26.50	-26	-206	381	215.90	-18.42	19.42	24.75	0
Oct	3	141.21	1.05	148.27	-145	-352	381	172.27	-43.63	46.63	94.58	0
Nov	129	144.49	0.95	137.27	-8	-360	381	168.55	-3.73	132.73	11.77	0
Dec	81	75.61	0.6	45.37	36		381	173.94	5.39	45.37	0.00	0

Table 7: Corn of land water balance in 1999 La Nina climate anomaly.

Month	P (mm)	ETP (mm)	kc Corn	ETc	P-ETc	APWL	Field capacity (mm)	Soil water content (SWC) (mm)	dSWC	ETa	Deficit	Surplus
Jan	134	32.32	1.05	33.94	100		381	381.00	0.00	32.32	0.00	102
Feb	72	113.83	0.95	108.14	-36	-42	381	343.57	-37.43	109.43	4.40	0
Mar	296	125.81	0.6	75.49	221		381	381.00	37.43	125.81	0.00	133
Apr	146	68.37	1.05	71.79	74		381	381.00	0.00	68.37	0.00	78
May	223	33.40	0.95	31.73	191		381	381.00	0.00	33.40	0.00	190
Jun	113	92.28	0.6	55.37	58		381	381.00	0.00	92.28	0.00	21
Jul	122	110.72	1.05	116.25	6		381	381.00	0.00	110.72	0.00	11
Aug	76	72.53	0.95	68.91	7		381	381.00	0.00	72.53	0.00	3
Sep	35	41.83	0.6	25.10	10		381	374.51	-6.49	41.49	0.35	0
Oct	160	118.86	1.05	124.81	35		381	381.00	6.49	118.86	0.00	35
Nov	138	133.16	0.95	126.50	11		381	381.00	0.00	133.16	0.00	5
Dec	92	73.47	0.6	44.08	48		381	381.00	0.00	73.47	0.00	19

water shortages when El Nino occurs. On the other hand, when La Nina lasts, the period of water availability on agricultural land will increase, thereby lengthening planting season and increasing planting intensity and production. However, excess water during La Nina needs to be anticipated, especially on land that is sensitive to inundation. Kaur *et al.* (2021) states that high temperatures can increase rate of evapotranspiration thereby increasing plant stress factors in the form of water stress accompanied by nutrient stress which will result in stunted growth and low corn seed production

In La Nina climate anomaly years, namely 2007-2008 and 2013-2014, there was an increase in corn production which reached 753,598 tons/year due to an increase in planting intensity caused by increased water supply for plants. This is indicated by coefficient of reduction in corn production which is categorized as very resistant to decreasing production. This is because in La Nina climate anomalies such as in 1999 there was a water surplus for 10 months which triggered an abundance of water availability during planting period of one year (Table 7). According to Nangimah *et al.* (2018) the positive impact of La Nina climate anomaly in form of increased rainfall during dry season can trigger an increase in planting intensity, especially in areas with a dry climate. Through Corn Agropolitan Program, Gorontalo provincial government is also implementing anticipatory strategies when El Nino and La Nina climate anomalies occur in form of using varieties that are resistant to drought and flooding, providing water pumps without engines, repairing irrigation channels and creating reservoirs in upstream areas as temporary water storage areas. Singh *et al.* (2017) suggests that climate anomalies can be facilitated by improving irrigation, developing plant varieties that require less water and heat resistant, using minimum tillage for practices to increase soil nutrient and moisture retention as well as regulating changes in planting and harvest times.

Potential accumulation of water loss

Based on Fig 1a and 1b, in the years of strong La Niño climate anomalies in 1999 and 2007 and 2008, the data shows that there was no accumulation of potential water

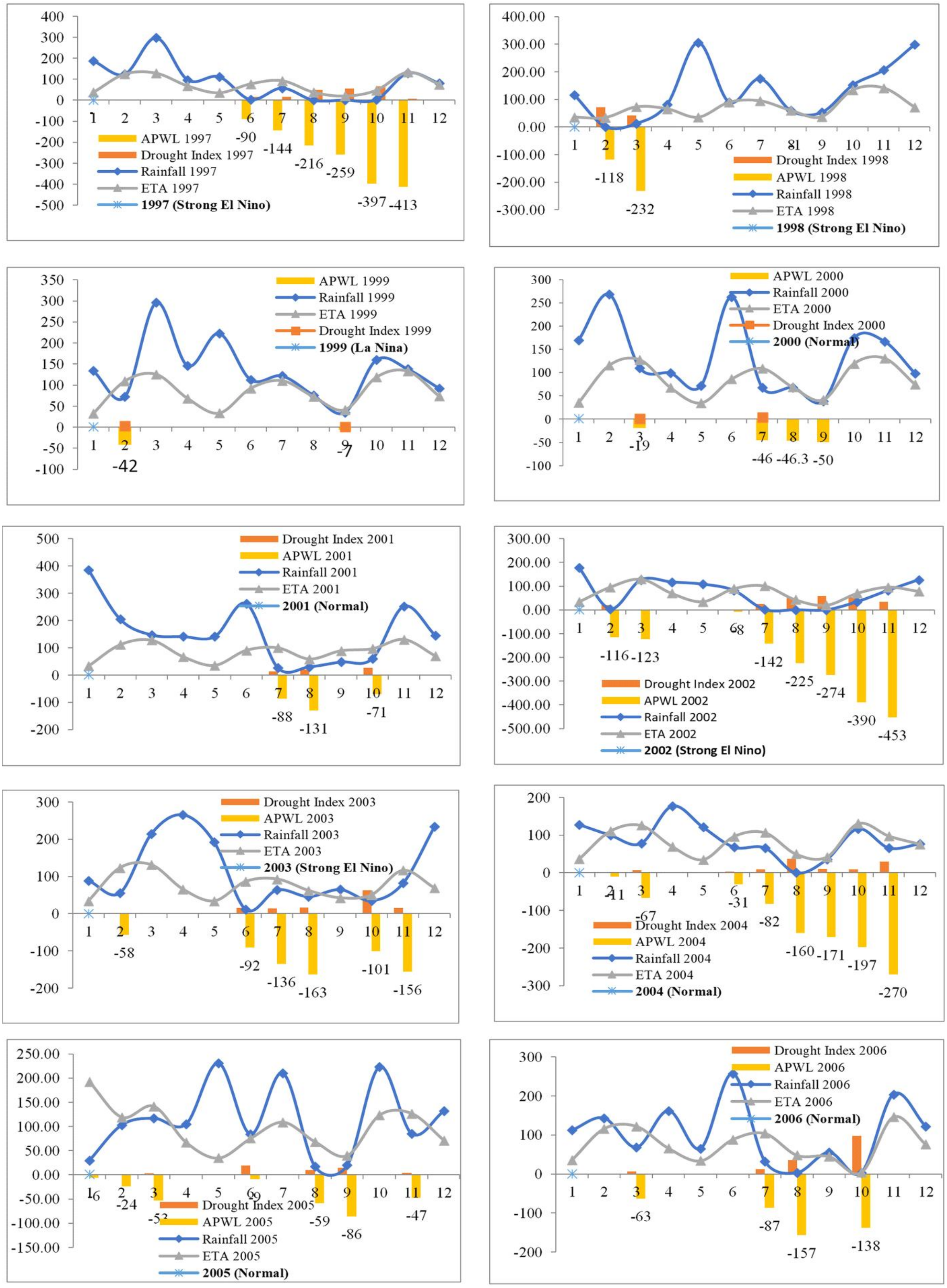

Fig 1 a: Graph of drought index and accumulated potential annual water loss 1997-2006.

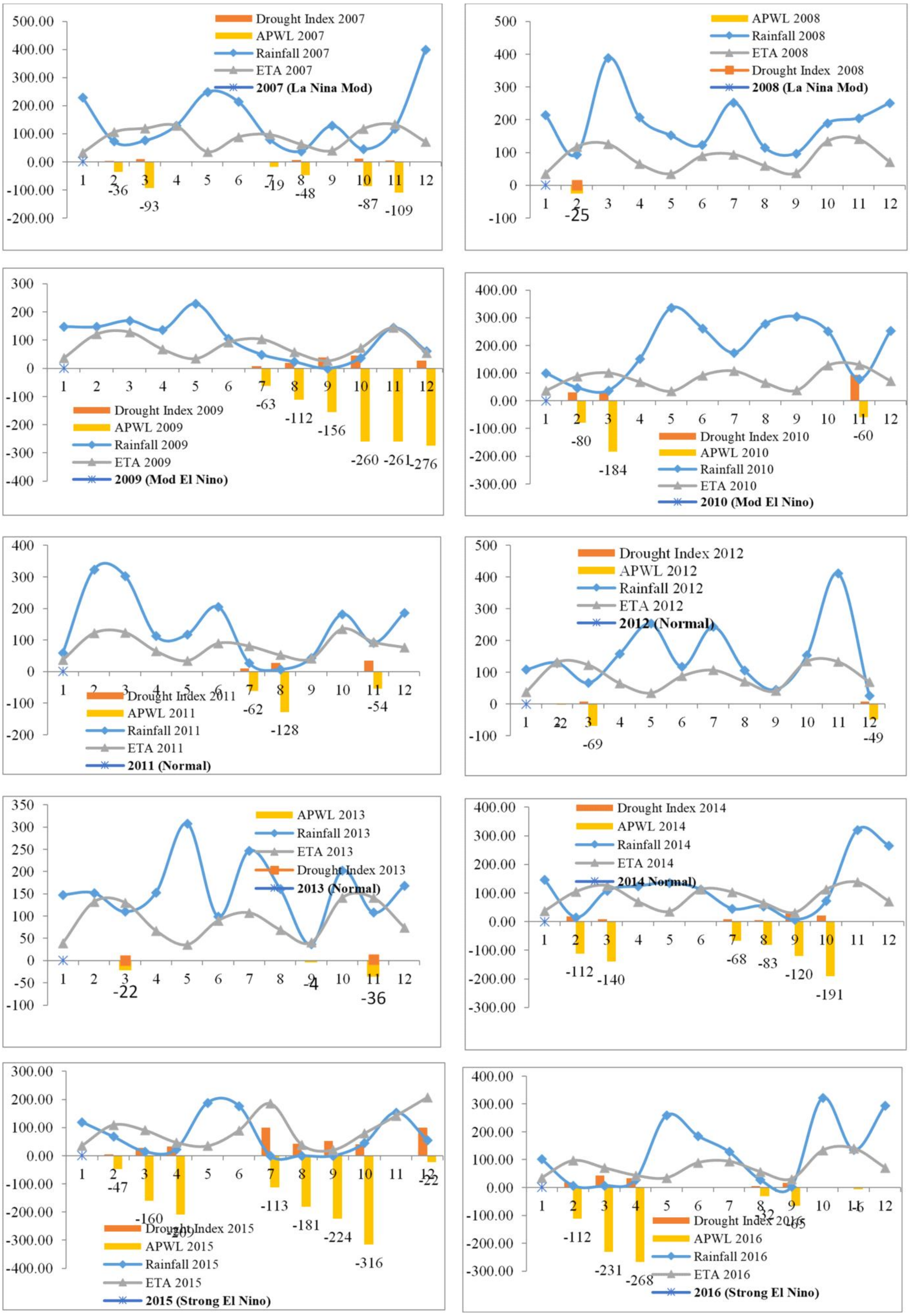

Fig 1 b: Graph of drought index and accumulated potential annual water loss 2007-2016.

loss, whereas in the years of strong El Nino climate anomalies, 1997-1998, there was an accumulation of potential water loss of 1869 mm. In 2015 and 2016 it was 1861 mm. In the moderate El Nino climate anomaly in 2002-2003 it was 2190 mm and in 2009-2010 it was 1392 mm. This triggers water stress and ultimately a water deficit due to extreme drought which can affect the productivity of maize plants. Igbadun *et al.* (2007) states that maize productivity is related to water availability which influences a number of subjects such as the maize varieties cultivated, soil water content per plant (deficit or surplus) and the irrigation technology applied. (Kheira, 2009) stated that the influence of water deficit in reducing maize seeds and crop biomass. In this study, it was found that water stress can affect components of maize production such as cob size, number of kernels per cob and plant seed weight.

Based on Fig 1a and 1b, in strong El Nino climate anomaly years, namely in 1997-1998, 2002-2003, 2015-2016 and moderate El Nino in 2009-2010, there was a large accumulation of potential loss due to the actual evapotranspiration accumulation rate (ETa). greater than monthly rainfall. This has an impact on reducing soil moisture due to large evapotranspiration rates and ultimately the water available to plants decreases which has an impact on plant water stress. Ko and Piccinni (2009) stated that treatment with a plant evapotranspiration rate (ETc) of 75% resulted in the reduction of maize seeds and triggered an increase in water use efficiency of 1.6 g m^{-2} mm^{-1}. Payero *et al.* (2009) stated that the water available in the soil is not enough to meet the water needs of maize plants during the planting period and that appropriate irrigation times are needed by considering the plant's evapotranspiration rate and the efficiency of plant water use to maximize maize production. (Krishna, 2019) stated that availability of groundwater on a spatial and temporal scale is necessary to maintain soil moisture which acts as a water source to meet plant water needs and crop water needs that are not met through irrigation sources. The evapotranporation process is main source of water loss that flows to the plant root zone which represents water needs from the atmosphere.

CONCLUSION

El Nino and La Nina climate anomaly patterns occur every 5 to 7 year recurring period. The highest level of drought with strong drought status occurred during the El Nino anomaly in 1997-1998 for 8 months and this triggered a decrease in harvested area and corn production with a coefficient of reduction in vulnerable production category. La Niña climate anomaly years 1999 and 2007 had an impact on low accumulation potential of water loss with highest level of drought weak status and this triggered an increase in harvested area and corn production with a coefficient of reduction in very resistant production category.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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