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Assessment of agricultural drought based on CHIRPS data and *SPI* method over West Papua – Indonesia

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Abstract: This study aims to utilise Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and Standardised Precipitation Index (*SPI*) method to assess agricultural drought in West Papua, Indonesia. The data used in this study is monthly CHIRPS data acquired from 1996 to 2019, daily precipitation data recorded from 1996 to 2019 from the five climatological stations in West Papua, Indonesia located at Sorong, Fakfak, Kaimana, Manokwari, and South Manokwari. 3-month *SPI* or quarterly *SPI* are used to assess agricultural drought, i.e., *SPI* January–March, *SPI* February–April, *SPI* March-May, *SPI* April–June, *SPI* May–July, *SPI* June–August, *SPI* July–September, *SPI* August–October, *SPI* September–November, and *SPI* October–December. The results showed that in 2019 agricultural drought in West Papua was moderately wet to severely dry. The most severely dry occurred in September–December periods. Generally, CHIRPS data and *SPI* methods have an acceptable accuracy in generating drought information in West Papua with an accuracy of 53% compared with climate data analysis. Besides, the *SPI* from CHIRPS data processing has a moderate correlation with climate data analysis with an average R^2 = 0.51.

Keywords: agricultural drought, Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data, Standardized Precipitation Index (*SPI*) method, West Papua – Indonesia

INTRODUCTION

Drought is one of the natural disasters in West Papua – Indonesia. Indonesian National Disaster Management Authority (Ind. Badan Nasional Penanggulangan Bencana) reported several areas in West Papua to have a high risk of drought: Manokwari, Raja Ampat, Teluk Bintuni, South Sorong, Teluk Wondama, Maybrat, and moderate drought threat: Sorong, Tambrauw, and Fakfak [NUGROHO *et al.* 2018].

Drought has a significant impact on agriculture. For example, the Food and Agriculture Organization documented that 83% of all damage and loss caused by drought was absorbed by agriculture which amounted to over USD 29 bln between 2005 and 2015 [FAO 2018].

The American Meteorological Society groups categorise drought into four groups; meteorological or climatological, agricultural, hydrological, and socioeconomic [HEIM 2002; WILHITE, GLANTZ 1985]. Meteorological drought is defined as the magnitude and duration of a precipitation shortfall. Agricultural drought links the various characteristics of meteorological drought to agricultural impacts and is commonly applied to non-irrigated agricultural regions. Hydrological droughts are related to the effects of periods of precipitation shortfall on surface or subsurface water supply. Socioeconomic drought is associated with the supply and demand of some economic good with elements of meteorological, agricultural, and hydrological drought.

Precipitation is the main meteorological variable with extensive applications for drought assessment and monitoring [DAS *et al.* 2016; KARAVITIS *et al.* 2011; MISHRA, NAGARAJAN 2011; NOSRATI, ZAREIEE 2011; ZHU *et al.* 2019]. Several drought indices based on precipitation data have been developed, including

Palmer Drought Severity Index (*PDSI*) [PALMER 1965], Effective Drought Index (*EDI*) [BYUN, WILHITE 1999], Standardized Precipitation Index (*SPI*) [GUTTMAN 1999], Deciles Index (*DI*), Percent of a Normal Index (*PNI*), Rainfall Anomaly Index (*RAI*), China-Z Index (*CZI*), Modified China-Z Index (*MCZI*), and Z-Score Index (*ZSI*) [SALEHNIA *et al.* 2017].

Among these indices, *SPI* is widely used for monitoring meteorological drought in the world. *SPI* has been used to monitor drought in Europe [EDO 2019], the United States [NOAA 2020], and Indonesia [BMKG 2020].

Researchers have tested the performance of *SPI*. According to KARAVITIS *et al.* [2011], *SPI* can describe the drought conditions in Greece very well, and the KUMAR *et al.* [2009] study shows that *SPI* under-estimates when precipitation is very low and very high.

XIA *et al.* [2018] reported that the 1-month *SPI*, 3-month *SPI*, and 6-month *SPI* are all more reliable than a 12-month *SPI* for drought monitoring in China. NOSRATI and ZAREIEE [2011] reported that the duration of precipitation data affected *SPI* accuracy in estimating drought levels in West Azerbaijan, Iran.

Traditionally precipitation is measured using a rain gauge (also called pluviometer, ombrometer, hygrometer, etc.). These methods provide a point estimation of precipitation and have low spatial representativeness of measurements.

West Papua, Indonesia had six climatological stations in 2020: Rendani – Manokwari, Ransiki – South Manokwari, Sorong – Sorong, Seigun – Sorong, Torea – Fakfak, and Utarom – Kaimana. Therefore, climate condition in West Papua – Indonesia cannot be fully represented (Fig. 1).

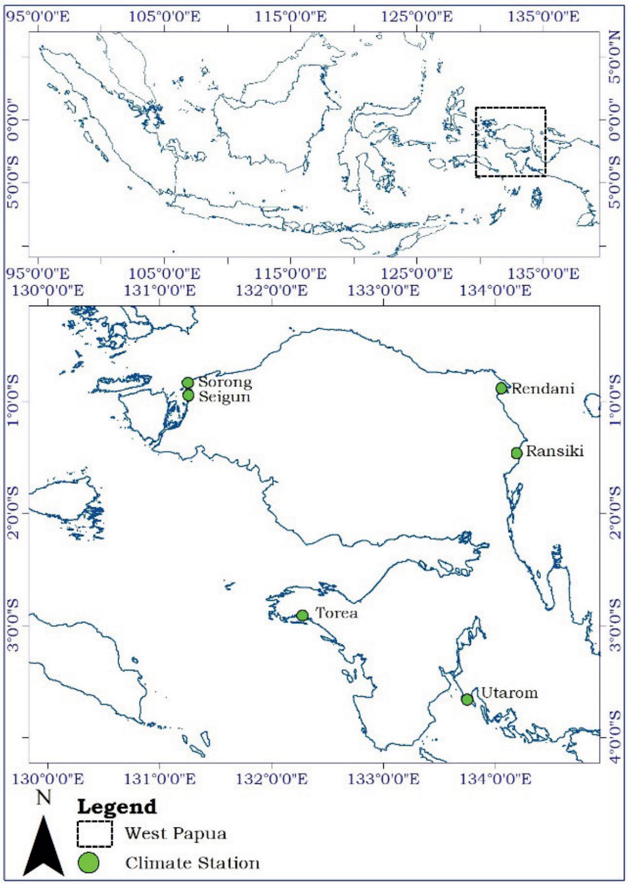


Fig. 1. Map of West Papua including climate station distribution; source: own elaboration

The utilisation of global precipitation satellite-based is expected to be an alternative solution. Global precipitation provides high resolution, both spatial and temporal resolution. In recent years, global precipitation products have been developed with algorithms that utilise multi-satellites and multi-sensors that consist of microwave sensors, geostationary infrared sensors, ground radar networks, and gauges for bias correction. An example of Global Precipitation Measurement (GPM), Tropical Rainfall Measuring Mission (TRMM), and Climate Hazards Group Infrared Precipitation with Stations (CHIRPS).

CHIRPS data is a quasi-global precipitation dataset that combines satellite observations, average precipitation from stations, and rainfall predictors such as elevation, latitude, and longitude to create gridded rainfall time series [FUNK *et al.* 2014]. CHIRPS data provides daily precipitation data from 1981 to near-real time with a 5 km spatial resolution.

Some studies show that CHIRPS data is very accurate in reproducing rainfall in East Africa [GEBRECHORKOS *et al.* 2018] and Eastern Africa with higher correlation and lower biases than station data [DINKU *et al.* 2018]. For example, MISNAWATI [2018] used CHIRPS data and *SPI* methods to assess agricultural drought in Central Java, Indonesia. MAHARANI [2019] used CHIRPS data to assess meteorological drought in East Java, Indonesia. The study shows that CHIRPS data closely follows the strongly correlated results compared with local data analysis.

MATERIALS AND METHODS

STUDY AREA

This research was conducted in West Papua, Indonesia. West Papua is the largest province in Indonesia with an area of 102,955 km^2 [BPS Provinsi Papua Barat 2019] and located at 1°12'07" N–4°24'04" S and 129°14'11" E–135°5'33" E.

PROCEDURE

Data inventory

A total of 288 monthly CHIRPS, data acquired from 1996 to 2019 and daily precipitation data recording from 1996 to 2019, from five climatological stations in West Papua, Indonesia located in Sorong, Fakfak, Kaimana, Manokwari, and South Manokwari were collected.

Standardised Precipitation Index (*SPI*) and drought classification

The World Meteorological Organization recommended a 3-month *SPI* or quarterly *SPI* for agricultural drought assessment [WMO 2012]. Standardised precipitation index calculated using the following equation [DAS *et al.* 2016; MISHRA, NAGARAJAN 2011; TOPÇU, SEÇKIN 2016; WIDODO 2013; WITONO, CHOLIANAWATI 2011]:

$$SPI = \frac{X_i - \bar{X}}{\sigma} \tag{1}$$

where: SPI = Standardized Precipitation Index, X_i = quarterly precipitation, $\bar{X}$ = average quarterly precipitation, σ = standard deviation of quarterly precipitation.

Dryness and wetness severity classifications according to the *SPI* values are listed in Table 1.

Table 1. The Standardised Precipitation Index (*SPI*) values and drought categories

***SPI* intervals**	**Drought category**	**Symbol**
≥2.00	extremely wet	EW
<1.50; 2.0)	very wet	VW
<1.00; 1.50)	moderately wet	MW
(–1.00; 1.00)	near normal	NN
(–1.50; 1.00>	moderately dry	MD
(–2.00; –1.50>	severely dry	SD
≤–2.00	extremely dry	ED

Source: WMO [2012], modified.

Evaluation

This stage aims to measure the accuracy of the CHIRPS data in detecting agricultural drought compared with climate data analysis. The accuracy of the CHIRPS data is calculated using the following equation:

$$A = \frac{H}{n} \tag{2}$$

where: A = accuracy, H = number of events when CHIRPS data and climate data analysis at the same level of drought; n = the number of data.

The scatter plot diagram is used in the analysis to determine the relationship between *SPI* CHIRPS and local data analysis. The general procedure for assessing the performance of CHIRPS data and *SPI* methods compared with station climate data analysis in predicting agricultural drought is shown in Figure 2.

RESULTS AND DISCUSSION

Based on the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and the Standardised Precipitation Index (SPI) method, agricultural drought in West Papua in 2019 was moderately wet to severely dry. The driest occurred September–December and the moderately wet, January–June. This is due to the highest quarterly precipitation with lower than average precipitation occurring in January–June and the lowest quarterly precipitation with higher average precipitation occurring in September–December.

The spatial distribution of quarterly precipitation in 2019, average quarterly precipitation, and a standard deviation of quarterly precipitation in West Papua based on the CHIRPS data processing are presented in Figures 3–5. The agricultural drought in West Papua in 2019 is based on the quarterly SPI shown in Figure 6.

Figure 3 shows that quarterly precipitation in West Papua tends to decline. The highest quarterly precipitation occurs in May–July, and the lower occurs in September–November. However, the trend of average quarterly precipitation in West Papua tends to increase. The highest average quarterly precipitation occurs in May–July, and the lower occurs in January–March. The trend of average quarterly precipitation is shown in Figure 4.

The quarterly precipitation in West Papua based on the monthly CHIRPS data acquired from 1996 to 2019 has a moderate deviation. The highest deviation of quarterly precipitation occurs in July–September, and the lower variation data occurs in March–May. The deviation of quarterly precipitation in West Papua is shown in Figure 5.

Generally, the drought level in West Papua, based on CHIRPS quarterly precipitation and *SPI* methods, is moderately wet to severely dry. The spatial distribution of drought levels in West Papua is presented in Figure 6. A comparison of *SPI* from

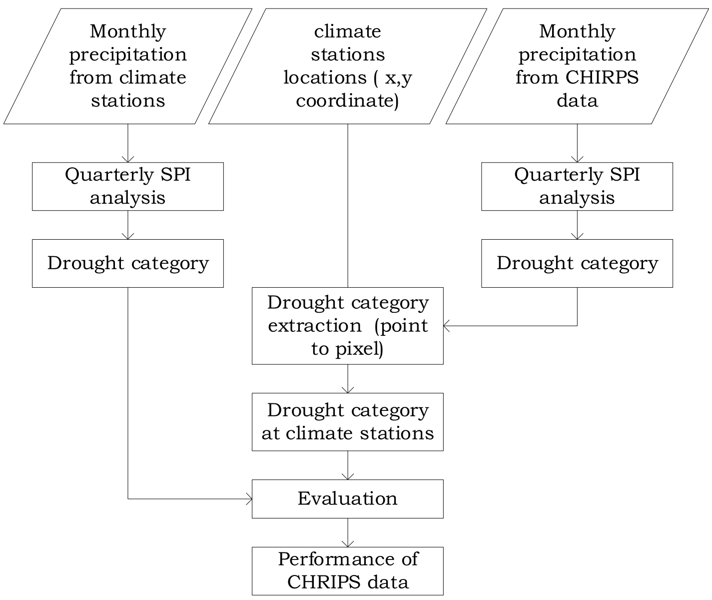


Fig. 2. General procedure for assessing the performance of Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and Standardised Precipitation Index (*SPI*) methods; source: own elaboration

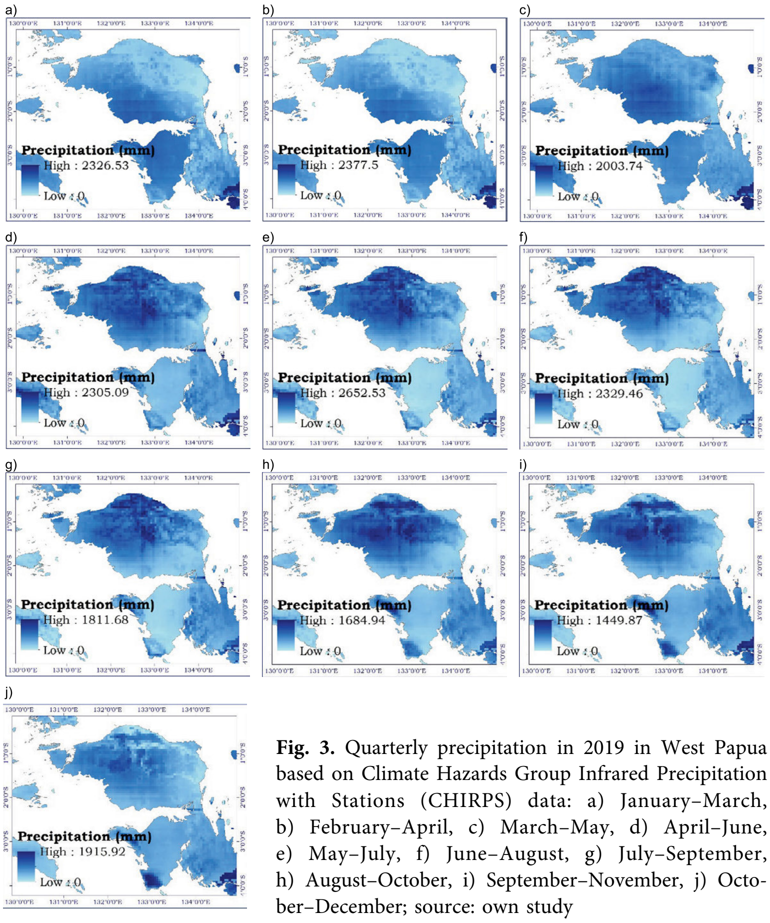


Fig. 3. Quarterly precipitation in 2019 in West Papua based on Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data: a) January–March, b) February–April, c) March–May, d) April–June, e) May–July, f) June–August, g) July–September, h) August–October, i) September–November, j) October–December; source: own study

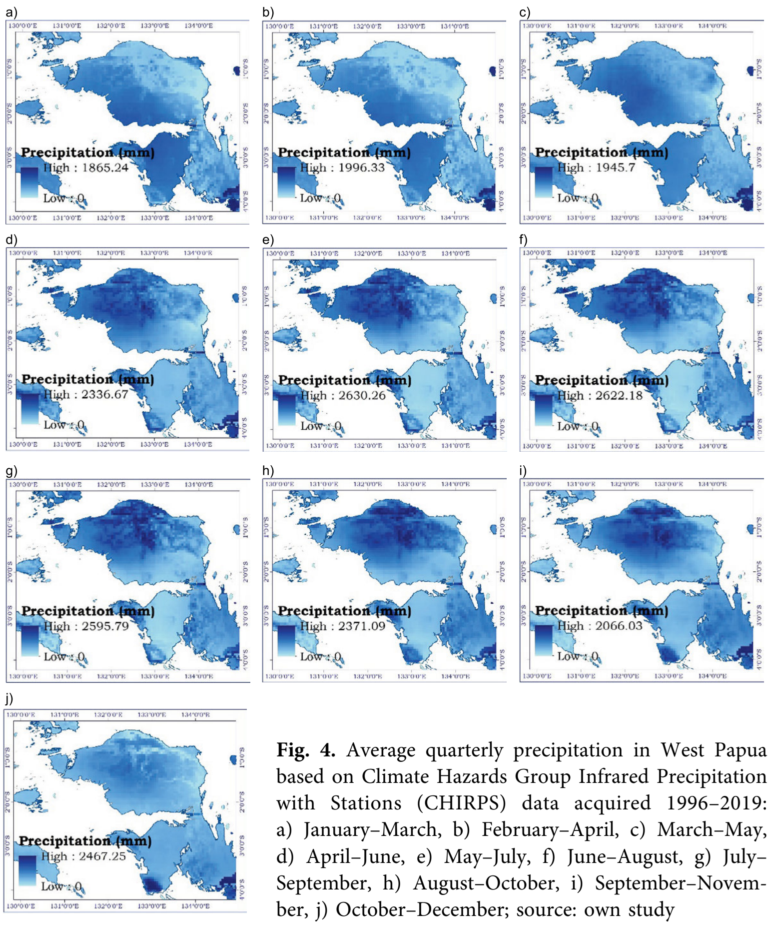
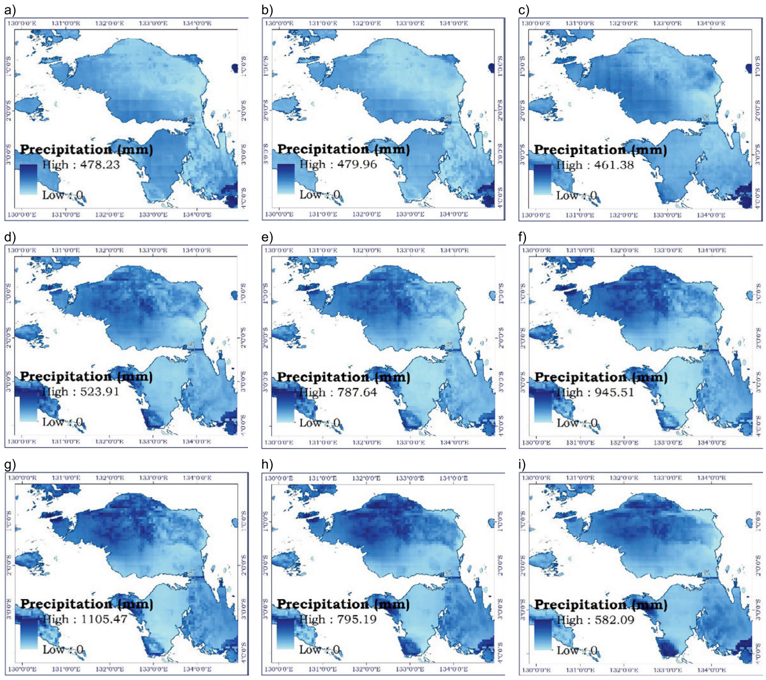


Fig. 4. Average quarterly precipitation in West Papua based on Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data acquired 1996–2019: a) January–March, b) February–April, c) March–May, d) April–June, e) May–July, f) June–August, g) July–September, h) August–October, i) September–November, j) October–December; source: own study



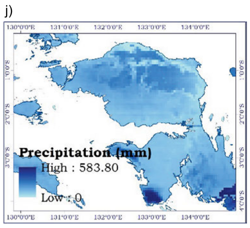
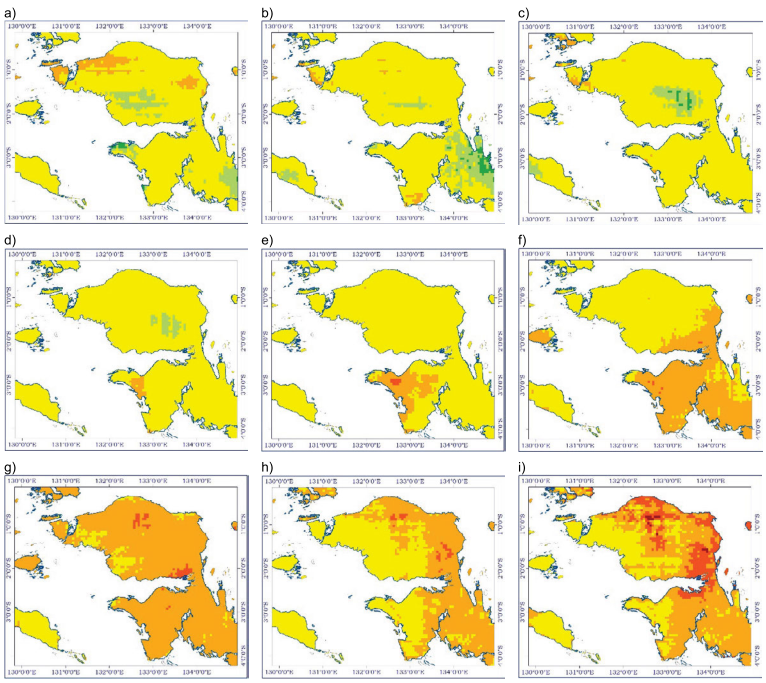


Fig. 5. The standard deviation of quarterly precipitation in West Papua based on Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data acquired 1996–2019: a) January–March, b) February–April, c) March–May, d) April–June, e) May–July, f) June–August, g) July–September, h) August–October, i) September–November, j) October–December; source: own study



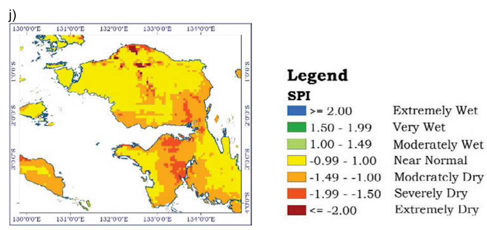


Fig. 6. Quarterly Standardised Precipitation Index (*SPI*) 2019 in West Papua based on Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data processing 1996–2019: a) January–March, b) February–April, c) March–May, d) April–June, e) May–July, f) June–August, g) July–September, h) August–October, i) September–November, j) October–December; source: own study

CHIRPS data and local precipitation data analysis is presented in Figure 7.

Generally, CHIRPS data and SPI methods have an accuracy of 53% compared with climate data analysis. However, several factors affected the accuracy, including the quality and duration of data used [MAHARANI 2019]. This is relevant to the research conducted by NOSRATI and ZAREIEE [2011] that the accuracy of *SPI* is influenced by the duration of data.

Besides, the *SPI* from CHIRPS data processing has a moderate correlation with *SPI* from climate data analysis with an average R^2 = 0.51. It is relevant to the research conducted by MISNAWATI [2018] and MAHARANI [2019].

A comparison of drought levels between the CHIRPS data and the climate data analysis is presented in Table 2. A correlation between *SPI* CHIRPS data and local precipitation data analysis is presented in the scatter plot diagram shown in Figure 8.

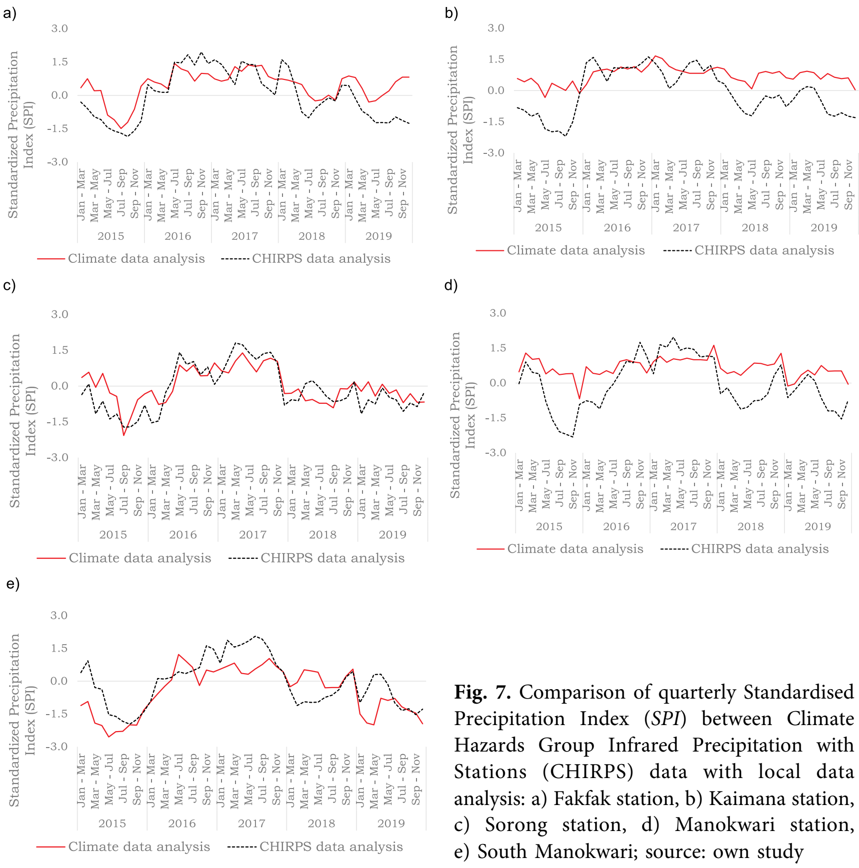


Fig. 7. Comparison of quarterly Standardised Precipitation Index (*SPI*) between Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data with local data analysis: a) Fakfak station, b) Kaimana station, c) Sorong station, d) Manokwari station, e) South Manokwari; source: own study

Table 2. Comparison of drought level between Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and climate data analysis

Period	Fakfak		Kaimana		Sorong		Manokwari		South Manokwari	
	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS
Jan–Mar 2015	NN	NN	NN	NN	NN	NN	NN	NN	MD	NN
Feb–Apr 2015	NN	NN	NN	NN	NN	NN	MW	NN	NN	NN
Mar–May 2015	NN	NN	NN	MD	NN	MD	MW	NN	SD	NN
Apr–Jun 2015	NN	MD	NN	MD	NN	NN	MW	NN	ED	NN
May–Jul 2015	NN	MD	NN	SD	NN	MD	NN	NN	ED	SD
Jun–Aug 2015	MD	SD	NN	SD	NN	MD	NN	SD	ED	SD
Jul–Sep 2015	MD	SD	NN	SD	ED	SD	NN	ED	ED	SD
Aug–Oct 2015	MD	SD	NN	ED	MD	SD	NN	ED	ED	SD
Sep–Nov 2015	NN	SD	NN	SD	NN	MD	NN	ED	ED	SD
Oct–Dec 2015	NN	MD	NN	NN	NN	NN	NN	NN	MD	MD

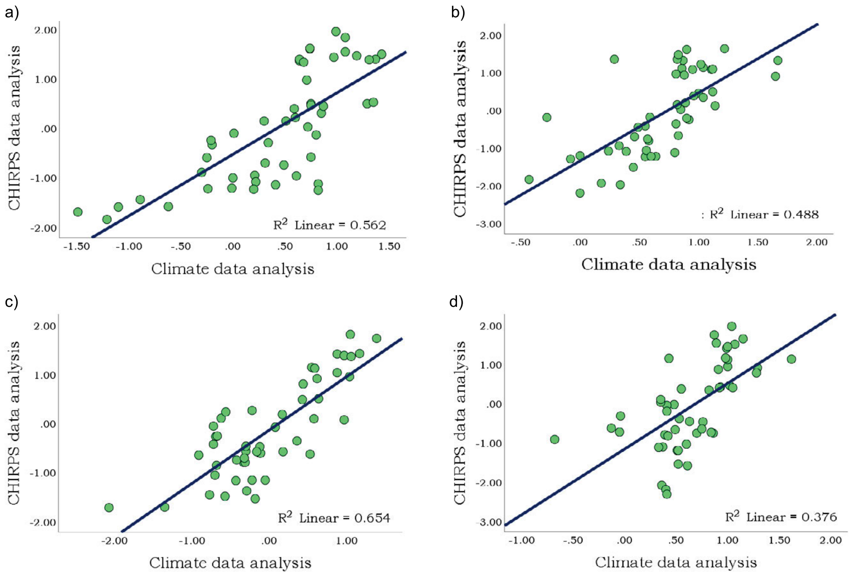
cont. Tab. 2

Period	Fakfak		Kaimana		Sorong		Manokwari		South Manokwari	
	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS
Jan–Mar 2016	NN	NN	NN	MW	NN	SD	NN	NN	NN	NN
Feb–Apr 2016	NN	NN	NN	VW	NN	MD	NN	NN	NN	NN
Mar–May 2016	NN	NN	NN	MW	NN	NN	NN	MD	NN	NN
Apr–Jun 2016	NN	NN	MW	NN	NN	NN	NN	NN	NN	NN
May–Jul 2016	MW	MW	NN	MW	NN	MW	NN	NN	MW	NN
Jun–Aug 2016	MW	MW	MW	MW	NN	NN	NN	NN	NN	NN
Jul–Sep 2016	MW	VW	MW	MW	NN	MW	MW	NN	NN	NN
Aug–Oct 2016	NN	MW	MW	MW	NN	NN	NN	NN	NN	NN
Sep–Nov 2016	NN	VW	NN	MW	NN	NN	NN	VW	NN	VW
Oct–Dec 2016	NN	MW	MW	VW	NN	NN	NN	MW	NN	MW
Jan–Mar 2017	NN	VW	VW	MW	NN	NN	NN	NN	NN	NN
Feb–Apr 2017	NN	MW	VW	NN	NN	MW	MW	VW	NN	VW
Mar–May 2017	NN	NN	MW	NN	MW	VW	NN	VW	NN	VW
Apr–Jun 2017	MW	NN	NN	NN	MW	VW	MW	VW	NN	VW
May–Jul 2017	MW	VW	NN	NN	NN	MW	NN	MW	NN	VW
Jun–Aug 2017	MW	MW	NN	MW	NN	MW	MW	VW	NN	EW
Jul–Sep 2017	MW	MW	NN	MW	MW	MW	MW	MW	NN	VW
Aug–Oct 2017	MW	NN	NN	NN	MW	MW	MW	MW	MW	MW
Sep–Nov 2017	NN	NN	MW	MW	MW	NN	NN	MW	NN	NN
Oct–Dec 2017	NN	NN	MW	NN	NN	NN	VW	MW	NN	NN
Jan–Mar 2018	NN	VW	MW	NN	NN	NN	NN	NN	NN	NN
Feb–Apr 2018	NN	MW	NN	NN	NN	NN	NN	NN	NN	MD
Mar–May 2018	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
Apr–Jun 2018	NN	NN	NN	MD	NN	NN	NN	MD	NN	NN
May–Jul 2018	NN	MD	NN	MD	NN	NN	NN	MD	NN	NN
Jun–Aug 2018	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
Jul–Sep 2018	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
Aug–Oct 2018	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
Sep–Nov 2018	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
Oct–Dec 2018	NN	NN	NN	NN	NN	NN	MW	NN	NN	NN
Jan–Mar 2019	NN	NN	NN	NN	NN	MD	NN	NN	SD	NN
Feb–Apr 2019	NN	NN	NN	NN	NN	NN	NN	NN	SD	NN
Mar–May 2019	NN	NN	NN	NN	NN	NN	NN	NN	ED	NN
Apr–Jun 2019	NN	NN	NN	NN	NN	NN	NN	NN	NN	NN
May–Jul 2019	NN	MD	NN	NN	NN	NN	NN	NN	NN	NN
Jun–Aug 2019	NN	MD	NN	MD	NN	NN	NN	NN	NN	NN
Jul–Sep 2019	NN	MD	NN	MD	NN	MD	NN	MD	MD	MD
Aug–Oct 2019	NN	NN	NN	MD	NN	NN	NN	MD	MD	MD

cont. Tab. 2

Period	Fakfak		Kaimana		Sorong		Manokwari		South Manokwari	
	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS	climate data	CHIRPS
Sep–Nov 2019	NN	MD	NN	MD	NN	NN	NN	SD	MD	SD
Oct–Dec 2019	NN	MD	NN	MD	NN	NN	NN	NN	SD	MD
H	26		22		32		26		27	
n	50		50		50		50		50	
Accuracy	0.52		0.44		0.64		0.52		0.54	

Explanations: NN, MD, MW, SD as in Tab. 1, *H* = number of events when CHIRPS data and climate data analysis at the same level of drought, *n* = the number of data.
Source: own study.



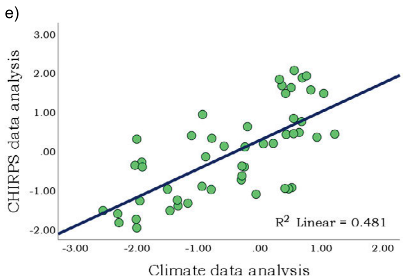


Fig. 8. Scatter plot of quarterly Standardised Precipitation Index (*SPI*) between Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and climate data analysis: (a) Fakfak station, (b) Kaimana station, (c) Sorong station, (d) Manokwari station, (e) South Manokwari; source: own study

CONCLUSIONS

Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) data and Standardised Precipitation Index (*SPI*) methods are acceptable in describing agricultural drought in West Papua. Besides, the *SPI* from CHIRPS data processing has a moderate correlation with climate data analysis. Therefore, CHIRPS data and *SPI* methods can monitor agricultural drought in West Papua.

Based on the studies, the CHIRPS data and *SPI* method can potentially be applied in other regions for agricultural drought monitoring, especially in areas with no precipitation data due to the unavailability of climate stations or rain gauges. However, testing still needs to be done.

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