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CHIRPS-based Spatio-temporal Rainfall Analysis as a Basis for Evaluating Cropping Pattern Suitability in Coastal West Sumatra

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Abstract. *Rainfall variability, in terms of amount, distribution, and timing, can increase the risk of crop failure and reduce crop yields. This study aimed to analyze CHIRPS (Climate Hazards Group InfraRed Precipitation with Stations) rainfall dynamics across several coastal areas of West Sumatra and to evaluate agroclimatic zones to assess the suitability of climate-adaptive cropping patterns. Monthly rainfall data for the period 1995–2024 were analyzed using the IDW interpolation method to produce rainfall distribution maps. This study also classified agroclimatic zones using Oldeman's classification to assess the suitability of cropping patterns. The analysis showed significant annual rainfall fluctuations, with high rainfall dominating the 1995–2014 period and a decline in the 2015–2024 period. Changes in monthly rainfall patterns, particularly the increase in rainfall from March to May during the 2015–2024 period, may have affected planting times and irrigation management. The three regions studied (Padang Pariaman Regency, Pariaman City, and Padang City) are in the A1 climate zone, with more than nine consecutive wet months, allowing year-round rice cultivation. However, rainfall fluctuations require adjustments in planting timing and the selection of secondary crops that are more drought-resistant. The results of this study provide a stronger basis for agricultural planning that is more adaptive to climate change, with recommendations for adjustments to the planting calendar and irrigation management to ensure the continuity of efficient and sustainable agricultural production.*

Keywords: *climate dynamics; cropping patterns; SDG 13; remote sensing.*

Type of the Paper: Regular Article.

1. Introduction

Rainfall variability, such as differences in amount, distribution, and timing, is a significant problem identified through rainfall data analysis. The main issue is uncertainty in determining optimal timing and planting patterns, which contributes to overall instability in agricultural yields [1–3]. Extreme and unpredictable changes in rainfall patterns make traditional methods of determining timing and planting patterns less effective. The implications are not limited to specific crops, but also increase the risk of crop failure across various types of commodities. With a better understanding of rainfall variability, adaptive strategies in agricultural planning, such as selecting planting patterns that are adaptive to climate fluctuations and implementing more efficient irrigation systems, can be applied to reduce losses and improve the overall resilience of agricultural

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production. This aligns with efforts to achieve SDG 13: Climate Action, which encourages mitigation and adaptation measures to address climate change to maintain agricultural sustainability and global food security [4–6].

The coastal zone of West Sumatra exhibits high rainfall variability both intra- and inter-annually, influenced by monsoon interactions, oceanic effects, and the orography of the Bukit Barisan range. As a result, the patterns and durations of the wet and dry seasons, and the frequency of extreme rainfall events, often undergo significant changes. In addition, global climate anomalies such as the El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) phenomena further exacerbate rainfall fluctuations in this region. The uncertainty in rainfall patterns directly affects the success of cropping patterns, especially on land with limited irrigation, such as rainfed rice fields. Coastal areas tend to be more vulnerable than non-coastal areas due to the direct influence of more complex ocean dynamics, including sea surface temperatures that can affect wind patterns and rainfall distribution in more extreme ways [7–10].

This study supports climate adaptation needs in coastal areas of West Sumatra by using rainfall dynamics as an empirical basis for evaluating the suitability of rice–secondary crop planting patterns and formulating more precise planting patterns to improve water use efficiency, productivity, and agricultural resilience [11]. To support a more accurate evaluation of climate conditions, remote sensing technology serves as an effective solution, including satellite products such as CHIRPS (Climate Hazards Group Infrared Precipitation with Stations) to obtain precise and reliable rainfall data. The use of CHIRPS as a basis for determining climate zones has been studied in various regions, both inside and outside Indonesia, with results showing a robust correlation ($r > 0.8$), slight relative bias (~6%), and excellent rainfall detection capabilities [12-19]. However, the evaluation of CHIRPS-based climate zones using current rainfall data remains limited to several coastal areas of West Sumatra. This study, therefore, makes a significant contribution by filling this gap. The findings of this study have the potential to support more adaptive and sustainable agricultural planning, particularly in the face of increasingly complex rainfall variability in these coastal areas.

This study analyzed rainfall dynamics using CHIRPS satellite products across several coastal areas of West Sumatra to evaluate changes in rainfall patterns that may affect cropping patterns. The main objective of this study was to understand climate variability, both in terms of rainfall amount and distribution, and its implications for the success of cropping patterns that are adaptive to climate change. This study integrated Oldeman's agroclimate zone classification [20] to determine climate types (A–E) and provide recommendations for cropping patterns better suited to the identified climate conditions, thereby improving the resilience and efficiency of agriculture in coastal areas of West Sumatra.

2. Materials and Methods

2.1. Study area

This study was conducted in three areas located in the coastal zone of West Sumatra Province (Padang Pariaman Regency, Pariaman City, and Padang City). The observation area covers a total area of 2,104.43 km², consisting of 17 sub-districts in Padang Pariaman Regency, four sub-districts in Pariaman City, and 11 sub-districts in Padang City (Fig. 1).

Fig.1. Research area: spatio-temporal rainfall analysis based on CHIRPS as a basis for evaluating the suitability of cropping patterns on the coast of West Sumatra

The rainfall data used were sourced from CHIRPS monthly data for a period of 30 years from 1995 to 2024 (https://www.chc.ucsb.edu/data/chirps). The data used in this study consisted of 360 files in raster format. The CHIRPS data, recognized as the best rainfall data provider choice, were obtained through reanalysis of satellite and observation data with a resolution of 5 km [21]. In addition to annual rainfall data, the other data used included the Digital Elevation Model (DEM), the Indonesian Topographic Map (RBI), and the administrative boundaries of West Sumatra data. The tools used in this analysis included ArcMap 10.8 and Microsoft Excel.

2.2. Research Methods

An experiment was conducted using descriptive survey and observation methods. Data processing began by using cell statistics to sum the monthly rainfall data for one year, resulting in 30 raster files representing annual rainfall data. Next, the cell statistics-mean tool was used to calculate the average annual rainfall for three 10-year periods (1995–2004, 2005–2014, and 2015–2024), resulting in three raster files. These raster files were then cut using square polygons and extracted into points using the Raster to Point tool. After that, interpolation was performed using the IDW method [22]. The next step was to calculate the area by converting the data from raster to vector format, followed by creating a map layout (rainfall parameter classes are presented in Table 1. The complete research flowchart is shown in Fig. 2.

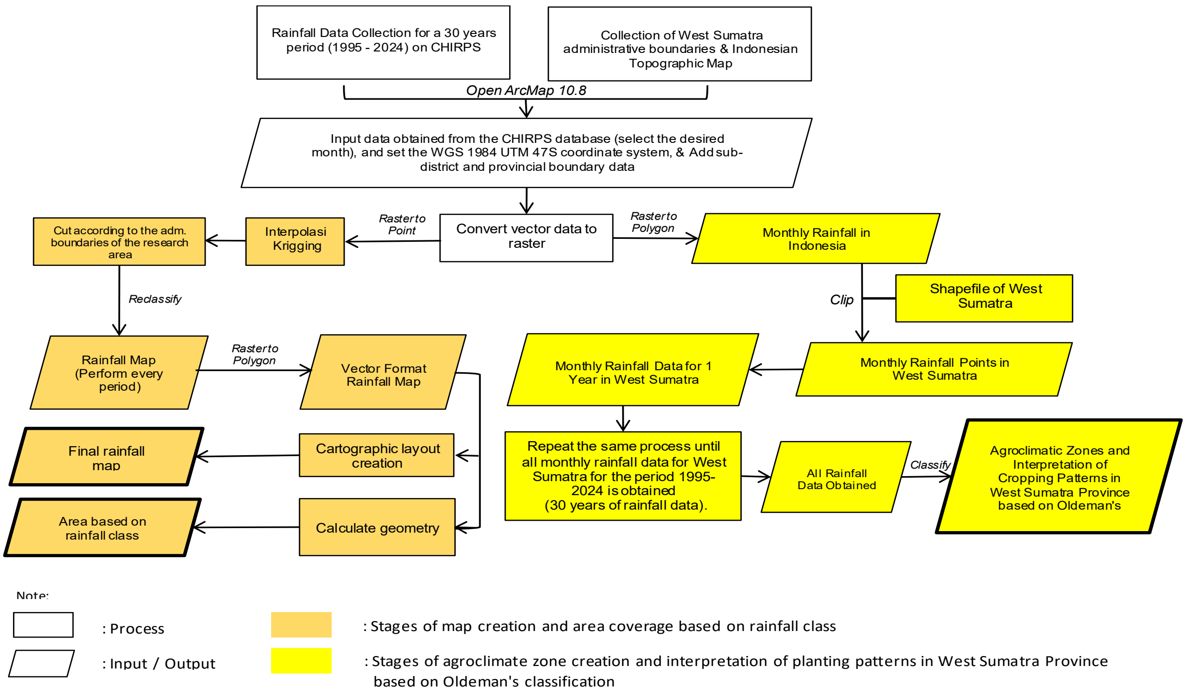

Fig. 2. Research flowchart

Data processing also produced a distribution of rainfall points in the observation area. These point data were then analyzed using IDW interpolation and overlay techniques. Based on Oldeman's criteria for wet and dry months, the interpolation data were compiled and classified according to Oldeman's zoning (Table 2).

Table 1. Classification of annual rainfall [23]

Rainfall (mm year^{-1})	Classification
0–500	
500–1,000	Low
1,000–1,500	
1,500–2,000	
2,000–2,500	Moderate
2,500–3,000	
3,000–3,500	
3,500–4,000	High
4,000–4,500	
4,500–5,000	Very High
> 5,000	

Table 2. Climate classification according to Oldeman [20]

Zone	Number of Consecutive Wet Months (Rainfall ≥ 200 mm month^{-1})	Sub-zone	Number of Consecutive Dry Months (Rainfall < 100 mm month^{-1})
A	> 9 months	1	< 2 months
B	7–9 months	2	2–3 months
C	5–6 months	3	4–6 months
D	3–4 months	4	> 6 months
E	< 3 months		

3. Results and Discussion

3.1.Annual Rainfall

Based on Table 3 and Fig. 3, the distribution of annual rainfall classes in the coastal zone of West Sumatra shows a clear shift in dominance between periods. In 1995–2004, the most significant proportion of area was in the 3,000–3,500 mm year^{-1} class (807.21 km²; 38.36%), followed by 2,500–3,000 mm year^{-1} (728.01 km²; 34.59%) and 3,500–4,000 mm year^{-1} (350.39 km²; 16.65%); the high annual rainfall classification of 4,000–4,500 mm year^{-1} did not appear in this period. In 2005–2014, there was a shift in dominance toward the 3,500–4,000 mm year^{-1} class (723.13 km²; 34.36%), followed by 3,000–3,500 mm year^{-1} (673.59 km²; 32.01%) and 2,500–3,000 mm year^{-1} (453.33 km²; 21.54%), along with the first appearance of the 4,000–4,500 mm year^{-1} class (225.48 km²; 10.71%). In 2015–2024, the dominance of 3,500–4,000 mm year^{-1} remained (764 km²; 36.30%) with a significant contribution from 3,000–3,500 mm year^{-1} (696.67 km²; 33.10%) and a renewed increase in the 2,500–3,000 mm year^{-1} class (568.20 km²; 27.00%), while the 4,000–4,500 mm year^{-1} class declined sharply (41.25 km²; 1.96%).

Table 3. Annual rainfall classification in several coastal areas of West Sumatra for the period 1995–2024

Rainfall (mm year^{-1})	Classification	Period 1995–2004		Period 2005–2014		Period 2015–2024	
		Area (km^2)	Percentage (%)	Area (km^2)	Percentag e (%)	Area (km^2)	Percentage (%)
0–500	Low	0	0	0	0	0	0
500–1,000		0	0	0	0	0	0
1,000–1,500		0	0	0	0	0	0
1,500–2,000	Moderate	6.79	0.32	1.95	0.09	2.09	0.10
2,000–2,500		212.04	10.08	26.92	1.28	32.22	1.53
2,500–3,000		728.01	34.59	453.33	21.54	568.2	27.00
3,000–3,500	High	807.21	38.36	673.59	32.01	696.67	33.10
3,500–4,000		350.39	16.65	723.13	34.36	764	36.30
4,000–4,500		0	0	225.48	10.71	41.25	1.96
4,500–5,000	Very High	0	0	0	0	0	0
> 5,000		0	0	0	0	0	0

Shifts and fluctuations in rainfall in the western coastal region of Sumatra reflect the unique climate dynamics of the area. Physically, precipitation concentrations along the west coast of Sumatra are influenced by coastal convection, land–sea circulation, and orographic uplift caused by the Bukit Barisan range. The interaction of coastal convection between warm land air and cool ocean air, as well as land–sea circulation that drives the movement of moist air from the sea to the land, also triggers the formation of rain clouds. The phenomenon of diurnal rainfall is also significant, with maximum rainfall occurring in the afternoon to the evening on land, then spreading to the coast in the early morning [24].

Based on previous research, this rainfall pattern is further strengthened during the active convective phase of the Madden–Julian Oscillation (MJO), which triggers increased convective intensity and stronger weather systems. MJO activity plays a vital role in increasing seasonal and annual precipitation accumulation, thereby affecting rainfall distribution patterns. Changes in rainfall patterns are significant to consider in agricultural planning, water resource management, and natural disaster mitigation, as in floods and landslides, which often occur due to extreme rainfall fluctuations in the region [25,26].

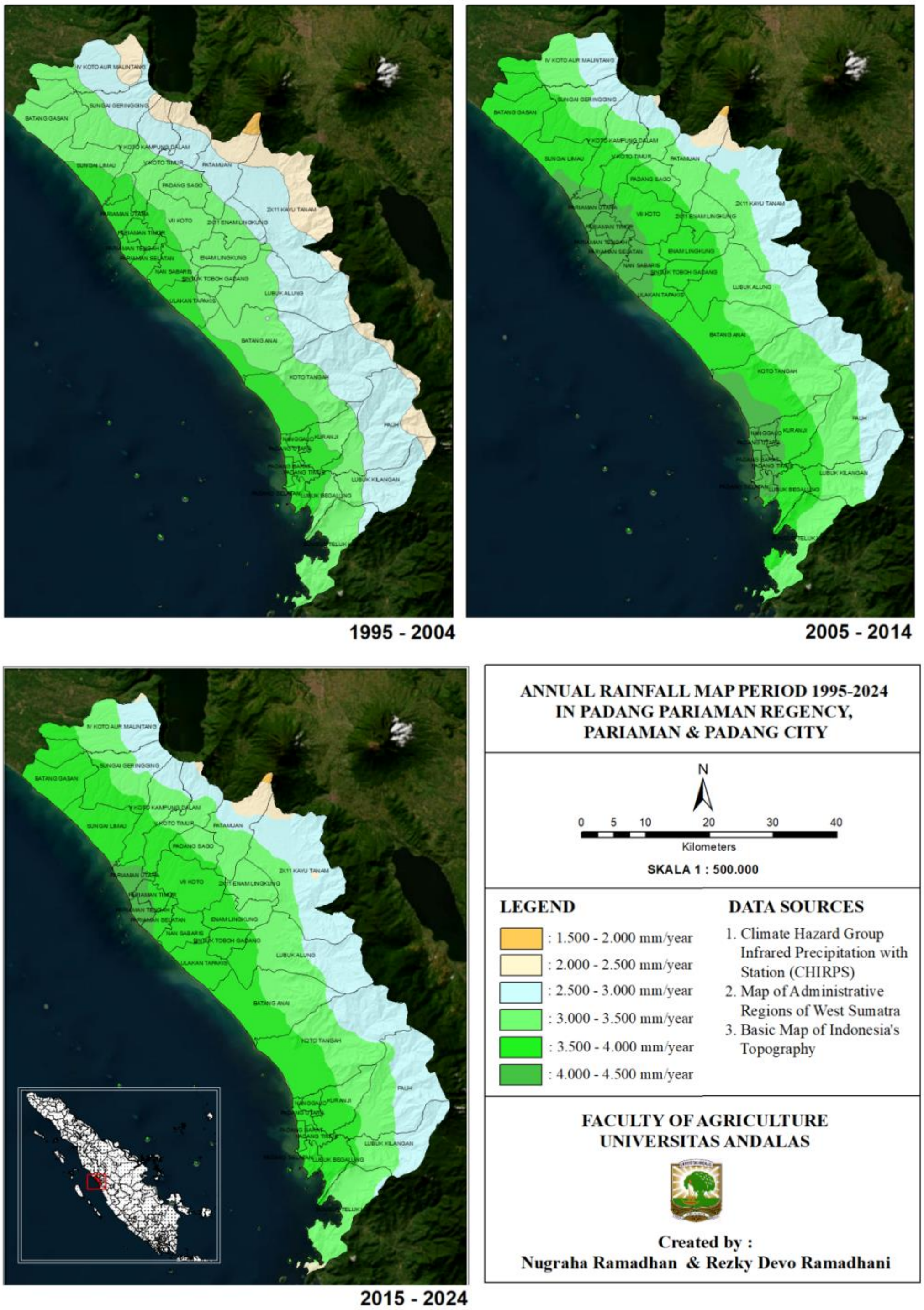

Fig. 3. Map of annual rainfall classification in several coastal areas of West Sumatra for the 1995–2024 period based on CHIRPS data

The instability of very high rainfall (4,000–4,500 mm year^{-1}) reflects modulation of interannual–interdecadal variability, likely associated with the combined ENSO and IOD phases, which influence convection and storms in Indonesia [27]. The extreme positive IOD in 2019 was documented to have suppressed rainfall in many regions of Indonesia and exacerbated land fires, thereby potentially reducing the annual contribution to the very high class during the 2015–2024 period [28]. From an agroclimatic perspective, the dominance of 3,000–4,000 mm year^{-1} since 2005 supports the intensification of two to three rice cropping seasons with good drainage and water management prerequisites [29], while the placement of secondary crops in relatively drier periods remains essential due to the sensitivity of yields, especially those of corn, to water deficits during the reproductive phase [30]. Optimizing operational planting time decisions can be aided by an integrated planting calendar system and ENSO information, which has been proven to provide economic benefits to rice farming in Indonesia [31].

3.2. Monthly Rainfall

Based on the monthly rainfall graph for 30 years (1995–2024) in Padang Pariaman Regency and Pariaman City, there was a shift in rainfall patterns and intensity between periods (Fig. 4). In the 1995–2004 period, the highest rainfall peaks occurred in October (396 mm; 468 mm) and November (388 mm; 461 mm), while July recorded the lowest rainfall (150 mm; 190 mm). During the 2005–2014 period, rainfall increased in several months, indicating higher variability compared to the previous period (1995–2004).

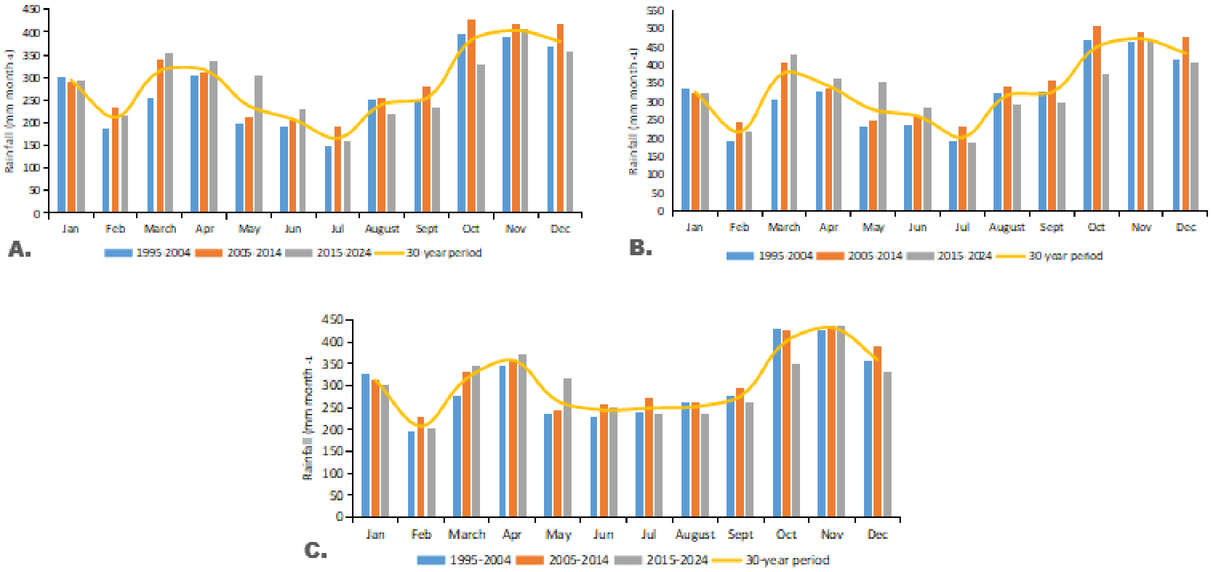

Fig. 4. Monthly rainfall based on CHIRPS in several coastal areas in West Sumatra, based on the period: A) Padang Pariaman Regency, B) Pariaman City, and C) Padang City

During the last period (2015–2024), the rainfall pattern was increasingly uneven compared to the preceding two periods, with a significant increase in March, April, May, and June, but the average rainfall decreased from July to December. In Padang City, the highest rainfall peaks in the 1995–2004 period occurred in October and November, while February was recorded as the month with the lowest rainfall. A similar pattern was observed in Padang Pariaman Regency and Pariaman City. In general, during the 2005–2014 period, there was an increase in average rainfall in almost every month in Padang City. However, during the 2015–2024 period, an increase in rainfall was only recorded from March to May compared to the previous period. This trend indicates a shift in the rainy season and an increase in rainfall anomalies, which could disrupt the readiness of agricultural land in Indonesia, particularly in determining planting times and water management [32,33].

The shift in rainfall patterns can be attributed to regional climate change that affects the Asian Monsoon and Sea Surface Temperature Anomalies in the Indian Ocean. A study by Mareta et al. [34] indicates that rainfall variability in West Sumatra is becoming increasingly influenced by the interaction between the Asian Monsoon and the Indian Ocean Dipole (IOD) phenomenon, resulting in a temporal shift in the rainy season. Based on Oldeman's agroclimatic zone classification, the rainfall pattern for the 1995–2024 period still shows a considerable number of wet months (> 200 mm month^{-1}), namely 11 consecutive months. This indicates that Padang Pariaman Regency is included in Agroclimatic Zone A1 (Table 2), which supports the implementation of three rice cropping patterns per year. However, the downward trend in rainfall at the beginning of the year (January–February) and the increase in March–April need to be overseen as they have the potential to shift the optimal planting period. As stated by Adriat et al. [35], changes in the timing of the rainy season's onset have affected the planting calendar in wet tropical regions, such as Indonesia.

3.3. Agrometeorological Zone

Based on Oldeman's climate classification, which refers to the number of consecutive wet months, Padang Pariaman Regency, Pariaman City, and Padang City are included in Climate Zone A1 (Table 4). This zone is characterized by a relatively long period of wet months, which supports rice cultivation. Padang Pariaman Regency has 11 consecutive wet months, while Pariaman City and Padang City experience 12 consecutive wet months. Thus, these three regions have a climate that is highly conducive to rice farming, allowing for the planting of rice in succession. The climatic conditions, characterized by consistently high rainfall throughout the year, provide advantages for the agricultural sector, particularly in supporting sustainable rice production in these regions. Additionally, the relatively even distribution of rainfall during the wet season also helps mitigate the risk of drought.

Table 4. Agroclimate zones of Padang Pariaman Regency, Paraman City, and Padang City based on Oldeman's classification

Location	Period 1995–2024												Zone
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Padang Pariaman	Wet	Wet	Wet	Wet	Wet	Wet	Humid	Wet	Wet	Wet	Wet	Wet	A1
Pariaman	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	A1
Padang	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	Wet	A1

(blue) : Wet Months
(yellow) : Humid Months

Areas with more than nine consecutive wet months (> 200 mm month^{-1}) have excellent potential for sustainable rice cultivation, given the abundant water availability throughout the year. However, several studies show that rice production in these areas tends to be low. This is mainly due to the low intensity of solar radiation flux, which is influenced by high cloud cover throughout the year. This decrease in solar radiation has a negative impact on the photosynthesis process, which in turn affects rice production in the region. Low solar radiation limits the photosynthesis process, thereby inhibiting the growth and filling of rice grains. This impact is most significant during the grain filling phase, where light deficiency reduces carbohydrate synthesis, lowers grain quality, and increases the likelihood of empty grains. In addition, stress due to low light also reduces root biomass production and affects the distribution of photosynthates to rice panicles [36–39].

4. Conclusions

Based on the current research on rainfall dynamics in the coastal region of West Sumatra, it can be concluded that annual rainfall patterns between 1995 and 2024 exhibit significant fluctuations. The period 1995–2004 was dominated by rainfall ranging from 3,000 to 3,500 mm year^{-1}, while in the period 2005–2014, the proportion of area with high rainfall (≥ 3,500 mm year^{-1}) increased. In the 2015–2024 period, rainfall intensity in the 3,500–4,000 mm year^{-1} class remained dominant, while that in the 4,000–4,500 mm year^{-1} class decreased, indicating greater fluctuations. These changes in rainfall patterns have the potential to affect existing cropping patterns, especially by influencing optimal planting times and irrigation management.

Changes in rainfall, especially in the early months of the year and increased rainfall from March to May, need to be taken into account when planning planting times. This requires adjustments to planting schedules and irrigation management to ensure the sustainability of efficient agricultural production. Based on Oldeman's climate zone classification identified in this study, the three regions studied are included in zone A1, which has more than nine consecutive wet months. This climate zone supports year-round sustainable rice cultivation. However, changes in rainfall patterns, such as decreased rainfall at the beginning of the year and increased rainfall in certain months, require adjustments in the selection of planting times and secondary crop types that are more resistant to the dry season. Therefore, this study provides a stronger basis for optimizing rice planting patterns and land use for secondary crops during periods of lower rainfall to achieve sustainable food security.

Abbreviations

ENSO	El Niño-Southern Oscillation
IOD	Indian Ocean Dipole
SDGs	Sustainable Development Goals
CHIRPS	Climate Hazards Center Infrared Precipitation with Station Data
DEM	Digital Elevation Model

MJO Madden–Julian Oscillation

Data Availability Statement

Data will be made available on request.

CRediT Authorship Contribution Statement

Nugraha Ramadhan: Data curation, conceptualization, investigation, formal analysis, methodology, project administration, resources, supervision, validation, map creation, writing-review and editing. Indra Dwipa: Data collection, analysis, and interpretation. Muhsanati: Supervising the data analysis and interpretation process. Winda Purnama Sari: Data collection, as well as assisting in coordinating supervision and all research activities. Afrima Sari: Data curation, formal analysis, investigation. Salsabila Amanda and Danang Nugroho: Assisting in data collection and analysis, Archiving and documenting all research activities. Rezky Devo Ramadhani: Assist in data processing and map creation. Rizky Armei Saputra: Supervising the data analysis and interpretation process.

Declaration of Competing Interest

The authors assert that they own no identifiable conflicting financial interests or personal ties that may have seemingly influenced the work presented in this study.

Declaration of Use of AI in the Writing Process

Nothing to disclose.

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