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Changes in Extreme Rainfall in New Capital of Indonesia (IKN) Based on 20 Years of GPM-IMERG Data

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Abstract

The Indonesian government has decided to relocate the nation's capital city from Jakarta on Java to the Nusantara Capital (IKN) on Kalimantan for political, socioeconomic, and infrastructure reasons, among others, including the threat of flood, earthquake, and land subsidence in Jakarta. However, IKN remains susceptible to hydro-meteorological disasters due to its equatorial location and high yearly rainfall amounts. In this article, we investigated changes in extreme rainfall in the IKN area over the last 20 years (2001-2020) based on Integrated Multi-Satellite Retrievals for GPM (IMERG) version 6 data. Overall, extreme rain in the IKN area, especially in the Sepaku and Semboja sub-districts, has slightly declined in the last 2 decades, as shown by negative and positive Sen's slopes of precipitation amount-based indices and the consecutive dry days (CDD), respectively. A decrease was also observed in RX1 day (annual maximum 1-day precipitation) and SDII (annual total rainfall divided by the number of wet days in the year) indices. This indicates that the IKN area is getting drier and could impact the availability of clean water in the future by increasing the intensity and duration of the drought. While the total amount of precipitation has decreased over the past 2 decades, there has been an increase in the intensity of more extreme precipitation events. This is evident from the rise in precipitation frequency-based indices (annual count of days with rainfall exceeding certain thresholds), such as R20mm and R50mm. The RX5day index (maximum 5-day precipitation) has also shown an increase. These changes increase the risk of flooding, so it is crucial to implement appropriate measures to mitigate the risk of floods in the IKN area.

Keywords: Extreme rainfall, New capital of Indonesia, IKN, IMERG

Introduction

Global warming is causing an increase in extreme weather trends around the world [1,2]. This is evident from the increasing frequency, duration, and intensity of extreme temperatures and rainfall in various parts of the world. The rise in extreme rainfall is linked to increased hydro-meteorological disasters such as floods, landslides, forest fires, droughts, and tornadoes [3]. However, different regions of the world respond differently to this trend, and areas with high water resources, such as island regions, are particularly vulnerable to the effects of global warming [4,5].

Administratively, Indonesia is the largest island nation in the world, with a land area of approximately 1.9 million km^2, 70 % of which is ocean [6]. Indonesia's land area is spread over more than 17 thousand islands of various sizes, making it the country with the longest total coastline in the world, at more than 99 thousand km [7]. Under these conditions, Indonesia is vulnerable to extreme weather conditions, which tend to increase. This can be seen in increased weather-related disasters, such as floods, landslides, forest fires, droughts, and tornadoes [8]. This hydrometeorological disaster threatens more than 270 million people in Indonesia.

The hydrometeorological disaster also occurred in Jakarta, which is the central government center. Jakarta is located in a coastal area and is therefore vulnerable to flooding, a problem that rising sea levels could exacerbate due to climate change [9]. The city's population has increased significantly in recent years, leading to a range of environmental and urban planning issues, including flooding [10], urban heat islands [11], air pollution [12], and river water pollution [13]. As a result, on August 26, 2019, the Indonesian government officially announced the relocation of the capital to parts of the North Penajam Paser Regency and Kutai Kartanegara Regency in the East Kalimantan Province [14]. The Indonesian government named the city Indonesia Nusantara Capital (IKN). Consequently, Jakarta's function as a government center has changed [15].

While IKN is not located in the Ring of Fire, which means there is minimal risk of disasters such as earthquakes, this area is still susceptible to hydro-meteorological disasters such as floods, landslides, and tornadoes caused by relatively high annual rainfall. Extreme rainfall events in Kalimantan are often associated with the monsoon season [16,17], characterized by heavy rainfall, strong winds, and high waves. During the monsoon season, the winds blow from the northeast, bringing moisture from the Pacific Ocean, which results in heavy rainfall over Kalimantan. The intensity and frequency of extreme rainfall events in Kalimantan have increased in recent years, attributed to climate change [18,19]. Warmer sea surface temperatures in the Pacific Ocean and Indian Ocean have increased atmospheric moisture content, which in turn leads to heavier rainfall events. Because rain in Kalimantan is influenced by atmospheric moisture content from the Pacific Ocean, the El Niño-Southern Oscillation (ENSO) also modulates extreme rain in Kalimantan [20]. In addition to climate change, deforestation and land-use change in Kalimantan have also contributed to the increase in extreme rainfall events [21]. The Madden-Julian Oscillation (MJO) can also significantly affect extreme rainfall events in Kalimantan. The MJO is a large-scale atmospheric wave propagating across the tropical Indian and Pacific Oceans. Recent studies have shown that the MJO is a significant driver of extreme rainfall events in Indonesia including Kalimantan [22].

Knowledge of extreme rainfall trends is of utmost importance for developing IKN because it can assist the government in infrastructure planning and disaster risk management. Extreme rainfall is closely linked to 5 key Sustainable Development Goals (SDGs): Zero hunger (Goal 2), Good health and well-being (Goal 3), Quality education (Goal 4), Clean water and sanitation (Goal 6), and Sustainable cities and communities (Goal 11) [23-25]. If not anticipated, extreme rainfall can lead to economic losses, hamper agricultural productivity, result in food shortages, disrupt the availability of clean water and adequate sanitation, and adversely affect urban infrastructure and settlements. By comprehending these changes, the government and related organizations can implement preventive and risk reduction measures to mitigate the resulting impacts.

Research on the trend of extreme rainfall in the specific IKN region has not yet been conducted. While there are studies that discuss the occurrence of extreme rain processes [26], long-term trends have not been explored. However, several studies conducted in broader areas include Kalimantan in their analyses. Supari *et al.* [27] examined rain gauge data from 1983 to 2012 in Indonesia and observed an increase in warm days and nights, as well as a decrease in cold days and nights. They also noted a declining trend in annual rainfall and an increase in Consecutive Dry Days (CDD). The Southeast Asia Regional Climate Downscaling/Coordinated Regional Climate Downscaling Experiment–Southeast Asia (SEACLID/CORDEX-SEA) model [28] also indicated increased CDD for Indonesia. However, the trend exhibited significant spatiotemporal variability, even at smaller scales. It is important to note that the aforementioned research, particularly those based on observational data, does not include the IKN area due to the absence of rain gauge stations in that region. Additionally, the trend of extreme rainfall is strongly influenced by the period of data coverage used. Variances in data periods can yield different trends. For instance, Villafuerte and Matsumoto [29] and Supari *et al.* [27] identified different extreme rainfall trends in Indonesia, likely attributable to the variation in data coverage periods. Consequently, it is crucial to analyze the trend of extreme rain in the IKN area using the most up-to-date data available.

This article investigates the changes in extreme rainfall within the IKN area over the past 20 years (2001 - 2020), utilizing Integrated Multi-Satellite Retrievals for GPM (IMERG) version 6 data. IMERG, a product developed by NASA and the Japan Aerospace Exploration Agency (JAXA), combines data from various satellite sensors to provide reliable global precipitation estimates [30]. IMERG data is precious for studying variations in extreme rainfall and other precipitation-related phenomena, often employed in hydrological, meteorological, and climate studies [31]. IMERG offers several advantages for analyzing extreme rainfall indices compared to other data sources. It boasts a high temporal and spatial resolution of 30 min and 0.1 °, respectively. This level of resolution enables the detection of intense rainfall events that rainfall products with lower temporal and spatial resolutions may miss. Moreover, integrating multi-satellite data within IMERG helps mitigate errors and biases associated with individual satellite observations. Moreover, IMERG data undergoes stringent quality control procedures involving comparisons with ground-based measurements and other satellite products to ensure accuracy and reliability [30,32,33]. Due to its exceptional spatial resolution (0.1 °), IMERG proves highly suitable for monitoring extreme rainfall trends in relatively small areas like IKN, where rain gauge stations are unavailable. Ramadan *et al.* [18] previously utilized IMERG data to investigate rainfall trends and their correlation with hydrometeorological disasters in the IKN area. However, their discussion primarily focused on the average extreme rain index for the entire IKN area, disregarding spatial variations. Consequently, this study serves as a follow-up to Ramadhan *et al.* [18] by examining the extreme rain index within each IMERG data grid specific to the IKN area.

Materials and methods

Study area

This research analyzes the changes in extreme rainfall in Indonesia's newly planned capital city (IKN). The IKN is situated on the island of Kalimantan, specifically in the East Kalimantan province (**Figure 1**). The designated planning area for developing the new capital city is North Penajam Paser Regency (PPU) and partially in Kutai Kartanegara Regency [14]. The sub-districts of Sepaku and Semboja have been the initial areas of development within the IKN. In addition to analyzing extreme rainfall in Sepaku and Semboja, this research also examines extreme rainfall in 2 neighboring cities, Samarinda and Balikpapan, as well as their surrounding areas, which serve as buffer areas. Buffer areas play an essential role in the development of IKN [34,35]. The presence of quality and integrated infrastructure in these buffer zones facilitates the movement of people, goods, and services to IKN. By providing affordable housing options, the buffer areas help alleviate the settlement pressure in IKN, accommodating the growing population of migrants or workers in the capital city. Moreover, well-developed buffer zones contribute to regional economic growth and the diversification of economic sectors, reducing excessive economic pressure on IKN while strengthening the national economy as a whole. Therefore, including an analysis of extreme rainfall trends in the buffer zones is crucial as it supports the effective functioning of IKN as the nation's capital city, ensuring optimal sustainability, safety, and prosperity.

The IKN area experiences bimodal rainfall patterns characterized by 2 distinct peaks in March-April and November-December. Monthly rainfall in the IKN area ranges from 108.51 to 317.00 mm/month, with an average of 230.24 mm/month. This seasonal rainfall pattern in the IKN area can be attributed to its proximity to the Inter-Tropical Convergence Zone (ITCZ). The ITCZ plays a significant role in influencing the region's rainfall distribution. The El Niño-Southern Oscillation (ENSO) also strongly affects the seasonal rainfall in the IKN area, particularly during the dry season in September-October. Moreover, the coastal location of the IKN area contributes to a dominant diurnal rainfall pattern. The highest accumulation of rainfall typically occurs in the afternoon, around 1400 - 1500 Local Standard Time (LST), near the IKN coastline or in the Semboja region. Subsequently, the peak of rainfall shifts to the nighttime, from 1600 - 1900 LST, in areas further away from the coastline or around the Sepaku area. For more detailed information on the climatological conditions of the IKN area, refer to the study conducted by Ramadhan *et al.* [18].

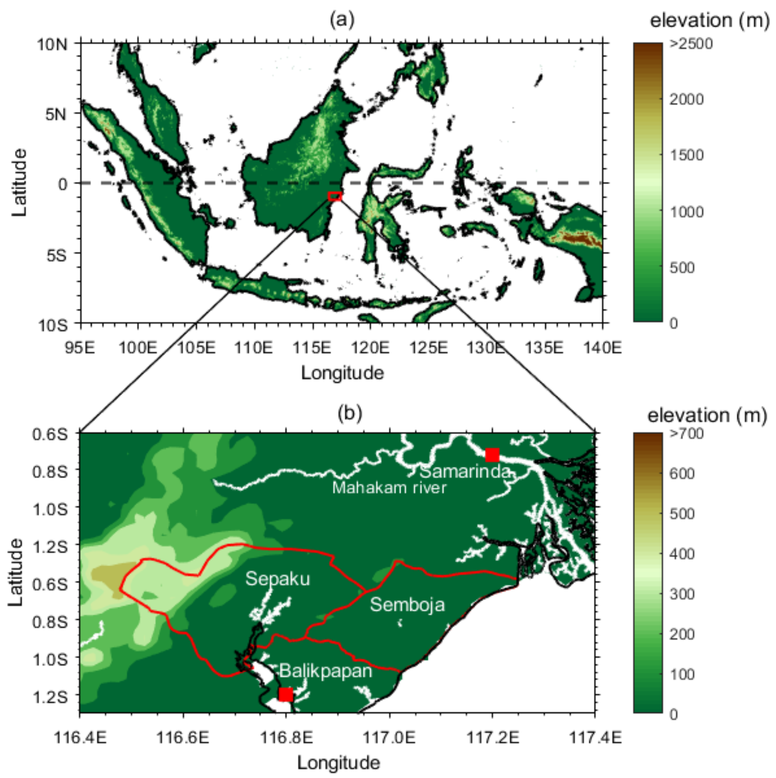

Figure 1 Topographic map of Indonesia including Malaysia and Republic of the Philippines (a) and location of new capital of Indonesia (b).

Integrated Multi-satellite Retrievals for GPM (IMERG) data

This research utilizes rainfall data from the Global Precipitation Measurement (GPM) product. GPM, launched in 2014 by NASA and JAXA, is the successor to the TRMM satellite and provides accurate and reliable global rainfall forecasts. GPM offers various products generated by different algorithms, including IMERG, a level-3 product. IMERG has a spatial resolution of 0.1 ° and a temporal resolution of 30 min. IMERG provides 3 types of products with different latencies: Early (IMERG-E), Late (IMERG-L), and Final (IMERG-F), with latencies of 4, 12 h, and 2.5 - 3.5 months, respectively [36]. For this study, we utilized daily data from IMERG-F Version 06. Several researchers have assessed the accuracy of IMERG for Indonesia and found that daily data from IMERG-F is relatively accurate [32,33,37,38]. The study utilized IMERG data spanning 20 years, from 2001 to 2020.

Methodology

The IMERG data were analyzed in this study to examine extreme rainfall patterns using the extreme rainfall indices provided by the Expert Team on Climate Change Detection and Indices (ETCCDI) (**Table 1**). The ETCCDI indices are widely recognized for their ability to identify extreme rainfall events in the context of climate change [39,40]. These indices encompass various categories, such as absolute, threshold, duration, and percentile indices, each employing different calculation methods [41]. All of these indices were utilized in this study to investigate extreme rainfall. The calculations were based on daily rainfall values extracted from the half-hourly data. Extreme rainfall indices were computed for each year and each grid.

Table 1 Definition of ETCCDI Indices used in this study [42].

Category	Name	Definition	Unit
Precipitation amount-based indices	PRCPTOT	Annual total of precipitation in wet days (days with precipitation ≥ 1 mm)	mm
	R85p	Annual total precipitation when RR ≥ 85th percentile of wet-days	mm
	R95p	Annual total precipitation when RR ≥ 95th percentile of wet-days	mm
	R99p	Annual total precipitation when RR ≥ 99th percentile of wet-days	mm
Precipitation duration-based indices	CDD	Maximum number of consecutive days with precipitation ≤ 1 mm	days
	CWD	Maximum number of consecutive days with precipitation ≥ 1 mm	days
Precipitation frequency-based indices	R1mm	Annual count of days when precipitation ≥ 1 mm	days
	R10mm	Annual count of days when precipitation ≥ 10 mm	days
	R20mm	Annual count of days when precipitation ≥ 20 mm	days
	R50mm	Annual count of days when precipitation ≥ 50 mm	days
	R100mm	Annual count of days when precipitation ≥ 100 mm	days
	R150mm	Annual count of days when precipitation ≥ 150 mm	days
Precipitation intensity-based indices	RX1day	Annual maximum 1-day precipitation	mm/day
	RX5day	Annual maximum consecutive 5-days precipitation amount	mm/5 days
	SDII	Annual total precipitation divided by the number of wet-days in the year	mm/day

To analyze the trend of extreme rainfall changes in IKN, Sen's non-parametric method [43] was employed. This method is commonly utilized to assess the magnitude of trends in time series data and is recommended by the World Meteorological Organization (WMO) for analyzing hydrometeorological trend data [44]. One of the advantages of using Sen's slope method is its ability to identify data trends independently of outliers and errors. The equation for Sen's slope, which applies to a dataset comprising N samples, is expressed as follows:

$$Qi = \frac{(X_j - X_i)}{j - i}$$

where Q_i is the estimate of Sen's slope, X_j and X_i are the values of a certain extreme index in years j and i, with the condition that $j > i$ and i = 1, 2, 3, ..., *N*. Thus, there will be $n(n-1)/2$ values of Q_i for *n* data points X_j. Furthermore, all the obtained Q_i values will be sorted from smallest to largest to calculate the median value of Q_i (Q_{med}). The Q_{med} value is calculated using a 2-tailed test estimation with a confidence level of 95 %.

Results and discussion

Table 2 presents the average values of all extreme precipitation indices in the vicinity of the IKN region (116.4°E -117.4°E, 1.25°S - 0.5°S). The spatial distribution of this mean value can be observed in previous studies [18]. The annual rainfall in the IKN area is relatively high, amounting to 2693.35 mm/year, with the number of wet days accounting for 49 % of the total days (177.86 days). The consecutive wet days (CWD) value reaches 15 days, while the consecutive dry days (CDD) value in the IKN area is relatively high at 25.86 days, indicating a potential for drought conditions. The maximum daily rainfall recorded reaches 172.24 mm/day, but the number of days with high intensity (R100mm) is relatively low, totaling 2.61 days. To examine the changes in extreme rainfall in the IKN area over the past 20 years, the Sen's slope of the extreme precipitation indices will be discussed in the subsequent sub-section.

Although the amount-based indices generally exhibit a decreasing trend, significant variability is observed between the land and coastal areas of the IKN region. This high variability is evident from the relatively large standard deviations of the slope for the amount-based indices in the IKN area, namely 13.06 (PRCPTOT), 10.50 (R85p), 8.20 (R95p), and 4.53 mm/year (R99p). The precipitation amount-based indices generally show a positive (negative) slope in the mainland (coastal) areas. Consistent with previous studies [18,28], the Sepaku and Semboja sub-districts exhibit a negative slope in the trend values. The decrease in precipitation amount in the central area of the IKN can potentially reduce the occurrence of hydrometeorological disasters such as floods. Decreased rainfall due to climate change can also impact the local ecosystems and biodiversity [45]. Besides deforestation, forest degradation, and development projects in IKN, climate change (global warming) is the main threat to biodiversity in this region. This can lead to reduced distribution and species abundance, especially endemics, which can even lead to extinction [45]. The increase in precipitation amount-based indices in the higher plains of the IKN region can increase the risk of river flow discharge in the central area, leading to potential hydrometeorological disasters. Additionally, the increase in amount-based indices will also impact the IKN buffer area, which is crucial in supporting the economic activities of the IKN. Infrastructure in the buffer area will support the mobility of people, goods, and services to IKN. Therefore, a natural disaster such as a flood in this area will disrupt economic activity in the IKN.

Table 2 Mean and standard deviation (Std) of extreme rainfall indices over IKN.

Index	Mean	Std
PRCPTOT (mm/year)	2693.35	771.84
R85p (mm/year)	1368.59	381.06
R95p (mm/year)	751.97	217.61
R99p (mm/year)	253.66	81.15
CDD (days)	25.86	17.20
CWD (days)	15.24	5.09
R1mm (days)	177.86	43.47
R10mm (days)	71.55	22.45

Index	Mean	Std
R20mm (days)	38.41	12.53
R50mm (days)	10.23	4.13
R100mm (days)	2.61	1.49
R150mm (days)	0.98	0.69
RX1day (mm/day)	172.24	48.63
RX5day (mm/5day)	260.49	66.25
SDII (mm/day)	15.10	2.45

Precipitation amount-based indices

Figure 2 shows the spatial distribution for the slope of the precipitation amount-based indices in IKN. All amount-based indices show a declining trend in the last 20 years with the average slope being −4.90 (PRCPTOT), −8.19 (R85p), −10.14 (R95p), and −0.98 mm/year (R99p). The largest decrease in slope was observed for the R85p and R95p indices, and the lowest was observed for the R99p index. The decrease in the amount of rainfall in IKN is consistent with the declining global rainfall trend due to global warming [44,46]. The amount of rainfall on the east and southeast coasts of the island of Kalimantan is also expected to decrease for the next few decades based on model projections [28], as can be seen clearly in **Figure 2**.

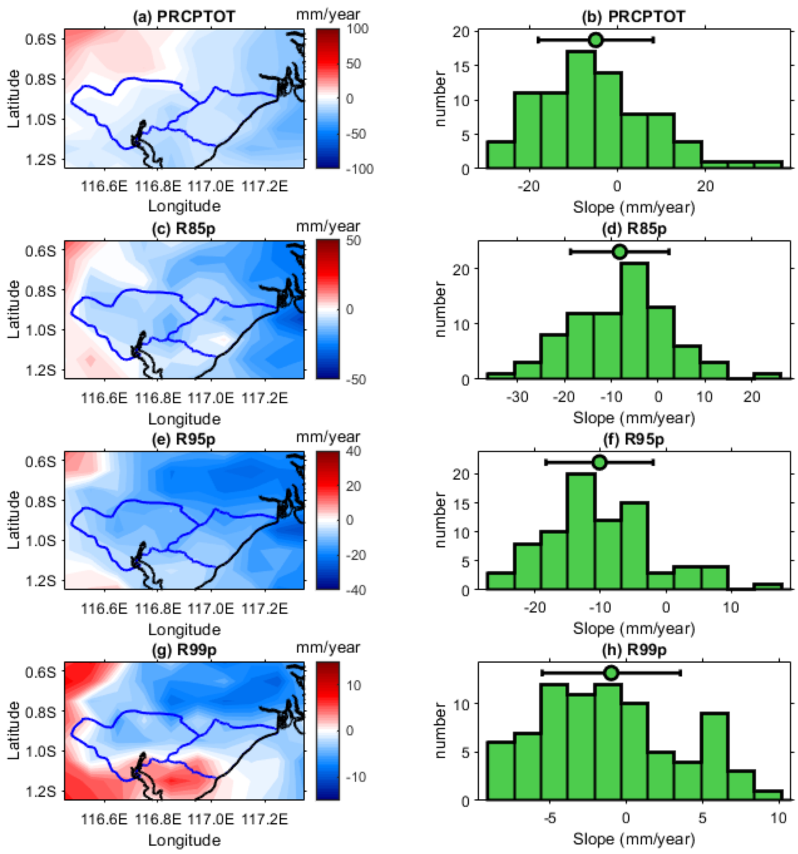

Figure 2 Spatial distribution of Sen's slope of precipitation amount-based indices (a) and their histogram (b). The error bars on the histogram show the mean and standard deviation values.

There can be several reasons for a decrease in global rainfall, including natural and human-induced factors. First, the decrease in precipitation amount-based indices can be attributed to the phenomenon of global warming. The rise in temperature, as evident from rain gauge data collected in Indonesia [27], leads to enhanced evaporation, resulting in drier soil surfaces and prolonged and intensified droughts. Despite the overall reduction in total precipitation amount, certain extreme indices demonstrate an upward trend, which can be attributed to the increasing intensity of the wet season and the escalating aridity during the dry season caused by the impact of climate change [47]. Second, deforestation can also cause a decrease in rainfall as trees play a crucial role in the water cycle [48]. Trees help to absorb water from the soil, and release it back into the atmosphere through a process known as transpiration. When trees are removed, this process is disrupted, leading to a decrease in rainfall. Third, the process of urbanization can also lead to a decrease in rainfall as concrete and other hard surfaces prevent rainwater from being absorbed into the ground. This can cause an increase in surface runoff and a decrease in groundwater recharge [49]. A significant decrease in vegetated land area is observed every year in the IKN area during last 20 years, followed by an increase in residential land and buildings (built-up area) and agricultural land [21]. This indicates deforestation and urbanization, which may cause a decrease in precipitation amount in the IKN. Rainfall patterns can vary naturally due to factors such as El Niño and La Niña events, changes in atmospheric pressure systems, and the position of the jet stream. These natural variations can cause a decrease in rainfall in some areas [20].

Although the value of precipitation amount-based indices tends to decrease, this value varies significantly for land and coastal area of IKN. Such high variability is observed from the relatively high standard deviation of the slope amount-based indices at IKN, namely 13.06 (PRCPTOT), 10.50 (R85p), 8.20 (R95p), and 4.53 mm/year (R99p). In general, the value of precipitation amount-based indices shows a positive (negative) slope in the mainland (coastal). For the Sepaku and Semboja sub-districts, the trend value shows a negative slope consistent with previous studies [18,39]. The precipitation amount that decreases in the central area of IKN can reduce the potential for hydrometeorological disasters such as floods. Inland regions may receive more rainfall due to orographic lifting [50]. Moist air is forced to rise over mountains or hills, leading to increased rainfall on the windward side and decreased rainfall on the leeward side. Increased precipitation amount-based indices in the higher plains of IKN will increase the risk of an increase in river flow discharge in the central area of IKN, which can also induce hydrometeorological disasters. In addition, the increase in precipitation amount-based indices will also affect the IKN buffer area, which is very important in supporting IKN economic activities, as described in the methodology section.

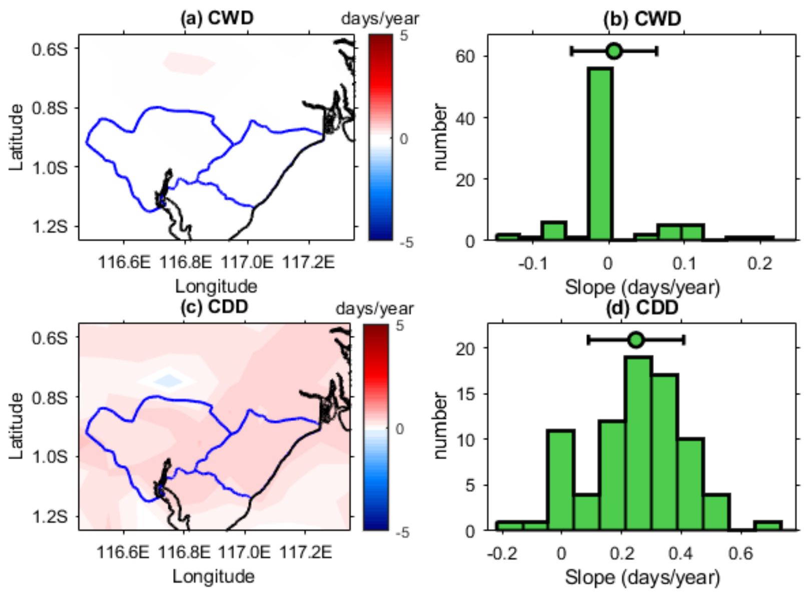

Figure 3 Same as **Figure 2**, but for precipitation duration-based indices.

Precipitation Duration-Based Indices

The value of duration-based indices in the IKN area shows an increasing trend in 20 years (**Figure 3**). A more pronounced increase was observed in the CDD index compared to the CWD index. The average slope of the CDD (CWD) in the IKN area is 0.25 (0.01) days/year with a standard deviation of 0.16 (0.01) days/year. The increase in CWD values in the IKN area is consistent with Ramadhan *et al.* [18]. However, a contrasting pattern was found for CDD values. This difference is probably due to differences in the extreme index trend analysis. This study estimates the extreme index for each grid, while Ramadhan *et al.* [18] combine all the data in IKN and calculate a trend from the combined data. Although duration-based indices have not shown a significant change trend in the last 20 years, the model projection shows that the value of CDD in the Indonesian region will continue to increase for the next few decades [20,28,39]. The increase in CDD is consistent with the decrease in precipitation amount-based indices (**Figure 2**), which is likely also related to climate change, deforestation, agricultural practices, and urbanization [21]. The annual mean of daily maximum temperature from rain gauge data for 30 years (1983 - 2012) shows an increasing trend [27], consistent with an increase in CDD. Thus, the increase in CDD in IKN can be attributed to the influence of climate change. Furthermore, deforestation and agricultural practices that involve removing natural vegetation cover can increase soil moisture loss and reduce the availability of water, leading to increased consecutive dry days. Urbanization can also impact CDD, as it can lead to increased surface runoff and reduced infiltration, which can decrease the amount of moisture in the soil and increase the number of consecutive dry days [51]. Prolonged CDD can lead to drought. The increase in CDD is consistent with the increase in the frequency and severity of droughts in the past 3 decades in Kalimantan [52]. It is important to take appropriate measures to mitigate the impacts of drought and prevent its escalation into a more severe disaster.

Precipitation frequency-based indices

Figure 4 illustrates the spatial distribution of the slope for frequency-based indices in the IKN area. Overall, the trend in frequency-based indices exhibits insignificant slope values. The R1mm index shows the largest slope value, with an average of 0.94 days/year. Positive slope values are also observed for the R10mm, R20mm, and R50mm indices, with averages of 0.27, 0.10, and 0.01 days/year, respectively. Conversely, the R100mm and R150mm indices display negative slope values, averaging −0.05 and −0.04 days/year, respectively. The average slope values of the frequency-based indices, which are not statistically significant, are accompanied by small standard deviations: 0.39 (R1mm), 0.28 (R10mm), 0.20 (R20mm), 0.08 (R50mm), 0.05 (R100mm), and 0.04 (R150mm). These insignificant trend values in the frequency-based indices align with the insignificant trends observed in the CWD and CDD. This non-significant trend of frequency-based indices is consistent with the long-term projection of the trend of the frequency of extreme rain events globally [53]. This insignificant trend value for frequency-based indices was also observed from extreme rain trends from rain gauge stations around the IKN area [28,39]. Overall, the analysis suggests no substantial trend in the frequency-based indices, indicating a relatively stable pattern of rainfall events in the IKN area.

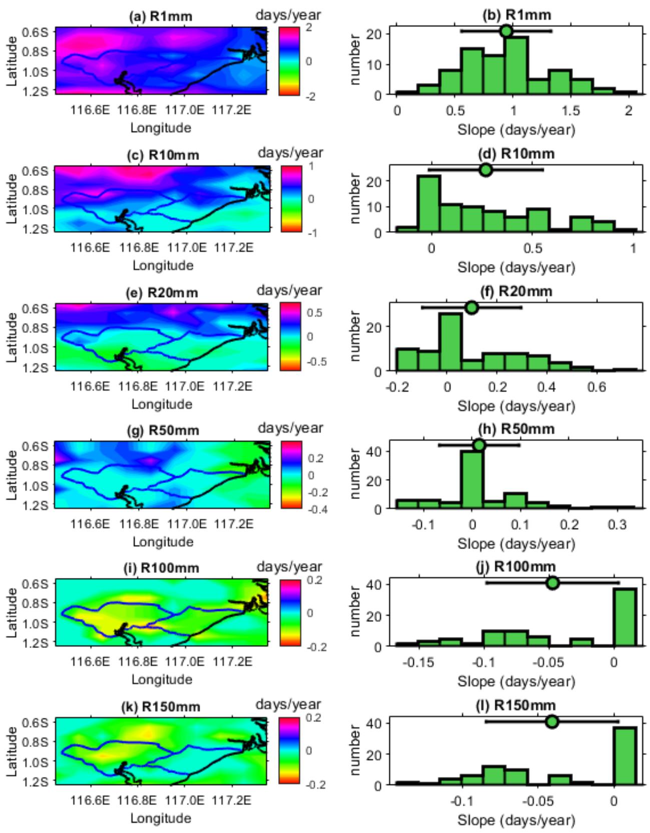

Figure 4 Same as **Figure 2**, but for precipitation frequency-based indices.

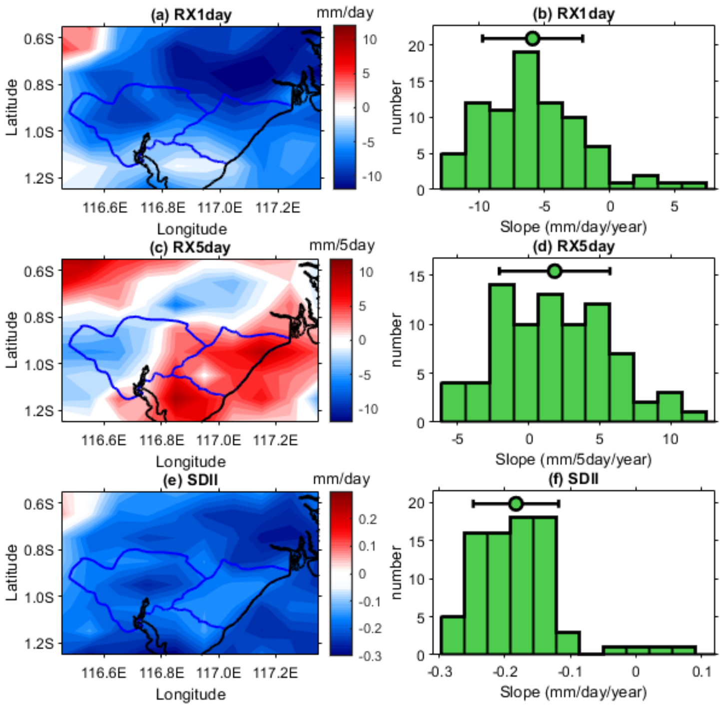

Figure 5 Same as **Figure 2**, but for precipitation intensity-based indices.

Precipitation intensity-based indices

Intensity-based indices show varying trend values (**Figure 5**). The RX1day and SDII indexes show a decreasing trend with an average slope of −5.86 and −0.18 mm/day/year. The declining trend of the RX1day and SDII indices is consistent with that found in previous studies [18]. This RX1day trend is also predicted to decrease further in the next few decades based on model projections for the east coast of Kalimantan [39]. Furthermore, the decrease in SDII values in the IKN area was caused by a decrease in the PRCPTOT value and an increase in R1mm in that region (**Figures 2(a)** and **3(a)**). Furthermore, an increasing trend was observed from the RX5day index with an average slope of 1.84, which is different from previous studies [18]. This difference is due to the high spatial variability of the trend index RX5day in the Sepaku and Semboja regions compared to RX1day and SDII, which is not observed by Ramadhan *et al.* [18] because they calculate the trend from the whole data rather than the individual grid.

High spatial variability of intensity-based indices was observed in the RX1day and RX5day indices. The standard deviation values of the RX1day and RX5day indexes are 3.84 and 3.89, while the SDII is only 0.07. Spatially, the RX5day value shows a positive increase for the coastline area and the northwest region of the IKN mainland. In addition to the increasing RX5day value in the northwest region of IKN, the RX1day value also shows a positive trend in that area. This is consistent with the result of Villafuerte and Matsumoto [29] based on the Asian Precipitation-Highly Resolved Observational Data Integration Toward Evaluation of Water Resources (APHRODITE) data for 57 years (1951 - 2007). This trend of increasing RX5day indicates an increase in the potential for river flooding in the IKN area, particularly in areas with slow-moving rivers or saturated soils. Areas with an increase in RX5day, especially in the northwest region of the IKN mainland, are also accompanied by an increase in the R20mm and R50mm indices. The RX5day increase has been observed globally using the Coupled Model Intercomparison Project phase 6 (CMIP6) simulation for several socioeconomic scenarios [54]. Intensified RX5day has the potential to heighten the likelihood of severe flooding, imposing significant economic burdens on various socioeconomic sectors. Excessive precipitation can result in severe floods that have detrimental effects on water quality and pose risks to human health and ecosystems [55]. Apart from flooding, heightened RX5day also amplifies the risk of landslides [55]. When consecutive precipitation exceeds normal levels, it raises the water table and saturates the ground, leading to the loss of stability in slopes and triggering landslides.

Conclusions

In general, there has been a slight decrease in extreme rainfall in the IKN area, particularly in Sepaku and Semboja sub-districts, over the past 20 years. This trend is evident from the negative values of Sen's slope for precipitation amount-based indices, including PRCPTOT, R85p, R95p, and R99p. This suggests a tendency for the region to become drier, supported by previous studies that utilized rain gauge observations [27] and model projections for the east coast of Kalimantan [28]. The increase in CDD and the SDII further indicate the potential for decreased rainfall in IKN. This decrease in rainfall can affect clean water availability and increase the risk of drought and forest fires. To ensure water security and resilience in IKN, it is crucial to implement several programs such as water conservation, efficient water management practices, sustainable land and forest management, and integrated water resources management. Additionally, continued research and technological innovation are needed to develop innovative solutions for water storage, conservation, and augmentation [56]. The decrease in rainfall also raises the potential for increased drought, particularly when accompanied by El Nino events during the dry season [18]. Therefore, it is essential to implement preventive measures, monitoring systems, early detection mechanisms, and plans for ecosystem restoration and the rehabilitation of burnt lands. While the overall trend suggests drier conditions in IKN, specific precipitation frequency-based indices, such as R1mm, R10mm, R20mm, and R50mm, indicate wetter conditions during certain periods within the region. This pattern aligns with global rainfall trends, where the rainy season is becoming wetter and the dry season is becoming drier [47]. Consequently, there may be an increased risk of runoff and flooding during the rainy seasons, while the dry seasons face an elevated drought risk and forest fires, as described earlier. Although this study utilized 20 years of data, its findings are consistent with previous studies. Therefore, it is important to consider the trends in extreme rainfall in IKN when planning for the region's development. It is worth noting that the duration of the data used in this study may have influenced the results. Thus, conducting analyses with longer data sets will be beneficial once sufficient samples are available. Furthermore, it is also necessary to project rainfall in the IKN under various land cover scenarios, as the existing projection from climate models were developed based on the conditions of the land before East Kalimantan was chosen as the location of the IKN.

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