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Effects of Land Cover Change and Deforestation on Rainfall and Surface Temperature in New Capital City of Indonesia

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Abstract: Land cover change and deforestation have a significant impact on climate change. This study investigates the effect of land cover change and deforestation on surface temperatures and extreme rainfall in the New Capital City of Indonesia (IKN), particularly in Samboja and Sepaku Subdistricts, East Kalimantan Province. Land cover change and deforestation were analyzed from Landsat 5 TM, 7 ETM+, and 8 OLI satellite data during 2001-2020. Land cover is divided into four classes: built-up land, water bodies, vegetation, and agricultural area. Rainfall data were obtained from the Integrated Multi-satellite Retrievals for GPM (IMERG) version 6 satellite, and extreme temperatures were taken from fifth-generation ECMWF reanalysis (ERA5) data. A significant decrease in vegetated land area is observed every year, followed by an increase in residential land and buildings (built-up area) and agricultural land. The highest rate of increase was observed in the area of agricultural land. Such change is correlated with an increase in surface temperature in the IKN. The strongest correlation is shown by increased built-up area and agricultural land. The relationship between rainfall and land cover is weak, and the body of water shows a relatively strong relationship. The extreme number of very wet days (R95p), consecutive dry days (CDD), and max 1-day precipitation (RX1day) rain index showed a decreasing trend during 2001-2020. However, the consecutive wet days (CWDs) index showed an increase. This needs to be a concern because consecutive precipitation extremes may cause more catastrophability than occasional extreme events.

Keywords: IKN; Land cover change; Deforestation; East Kalimantan

Introduction

Changes in land cover and deforestation are closely related to climate change (Ngaji, 2016). These two activities contribute to the increase in temperature and carbon concentration. According to the Intergovernmental Panel on Climate Change(Panel & Change, 2016), the average global surface temperature has increased at a rate of 0.74°C ± 0.18°C over the last hundred years. The IPCC's latest report (Masson-Delmotte et al., 2021) indicated that the world could achieve or exceed 1.5 degrees C of warming in just two decades. In addition, about 1.6 billion tonnes of carbon are emitted annually by land use change activities, of which the most prominent part comes from deforestation and forest degradation. Changes in land cover cause an increase in the concentration of CO2 in the atmosphere (Tokairin et al., 2010).

Indonesia is a country with abundant natural resources, including forests. Forest resources in Indonesia have a promising economic function. However, environmental damage is also relatively high in Indonesian forests. The forest area in Indonesia changes every year. Based on data published by the Indonesian Ministry of Environment and Forestry during 1990–2013, the total forest loss in Indonesia was around 19.7 million hectares or 0.822 million hectares per year (Nishioka, 2016). The forest area in Indonesia in 2019 was only 94,114.1 hectares. This environmental damage, including forests, allegedly contributes to recent climate change. Climate change has caused several impacts, such as (a) the entire territory of Indonesia experiencing an increase in air temperature,

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(b) the southern region of Indonesia experiencing a decrease in rainfall, and the northern region experiencing an increase in rainfall. Changes in rain patterns cause changes in the beginning and length of the rainy season (Julismin, 2013).

Changes in forest area are closely related to changes in land use. One of the areas experiencing the largest change in forest cover and deforestation in Indonesia is East Kalimantan. According to data from FWI (Forest Watch Indonesia), the migration rate of deforestation and forest degradation in East Kalimantan increased significantly from 89 ha/year to 157 ha/year. This is also related to the Indonesian government's decision to relocate the capital of Indonesia from Jakarta to East Kalimantan (Novita & Vonnisa, 2021).

The use of remote sensing technology has provided valuable information regarding the impacts of land change on climate, including in Indonesia. Comarazamy et al (2013) and Iswati et al. (2013) investigated the effects of land cover on climate change anomalies in the tropics and Kalimantan, respectively. They found that global warming increases maximum temperature and wind speed gradient. The latest research was conducted by Putri (2017) on changes in land cover on surface temperature in the city of Jambi using Landsat 7 imagery data. They found that land cover has a very close relationship with surface temperature. However, this study only discusses the effect of land change on surface temperature. Then Zhao and Pitman (2002) investigated land cover changes in convective rainfall. They simulated the relationship between land cover change and CO2 levels. The results indicate that the increase in CO2, which is undoubtedly related to land cover, causes an increase in maximum temperature and changes in rainfall intensity. While there have been some studies on the impacts of land change on climate change in Indonesia, such study for the new capital city of Indonesia (hereafter called IKN) is still minimal. In fact, the level of environmental damage, including land change and deforestation in IKN, is relatively high. The extreme rain that occurred in IKN has caused a lot of hydrometeorological disasters such as floods, flash floods, landslides, and so on (Ramadhan et al., 2022)

This study investigated the effect of land cover change and deforestation on rainfall and surface temperature in the IKN area (Figure 1), especially in in Semboja and Sepaku Subdistricts. Land cover and deforestation were processed from Landsat satellite data. Surface temperature data is taken from European Center for Medium-Range Weather Forecasts (ECMWF) ERA 5, and rainfall data is derived from Integrated Multi-satellite Retrievals for GPM (IMERG).

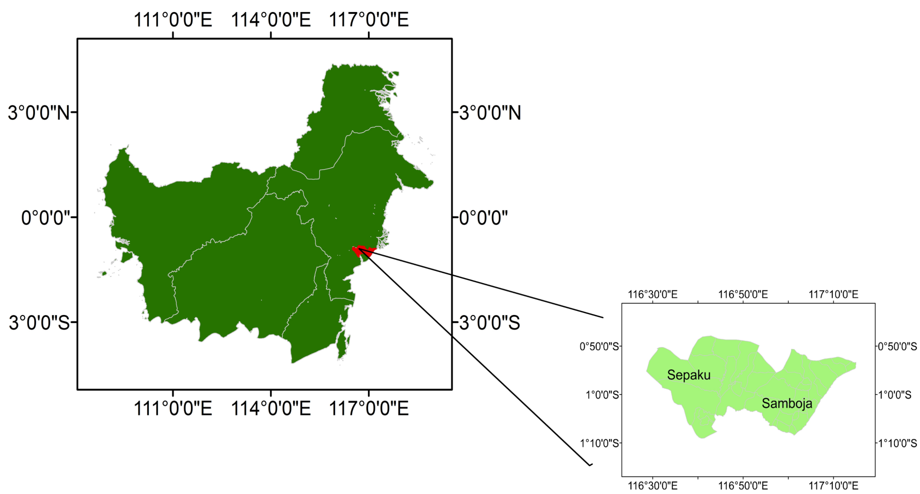

Figure 1. Research location in Sepaku and Samboja sub-districts (East Kalimantan).

Method

This study uses Landsat 5 TM, 7 ETM+, and 8 OLI images in 2001, 2004, 2008, 2012, 2016, and 2020. Land covers are classified into four classes: vegetation, agricultural land, built-up land, and water bodies. Precipitation was obtained from Integrated Multi-satellite Retrievals for GPM (IMERG) version 6 data, and extreme temperatures were observed from ECMWF Reanalysis (ERA5). The spatial resolution of the IMERG data is 0.1°, and the temporal resolution is 30 minutes. For ERA5, the spatial and temporal resolutions used are 0.25◦ and 1 hour. Several studies have evaluated the accuracy of IMERG data in Indonesia (Ramadhan, et al., 2022a; 2022b; 2022c; 2022d). In this study, the validation procedure of IMERG data was the same as the previous study by (Ramadhan, et al., 2022a; 2022b; 2022c; 2022d).

Data processing consists of two stages, namely pre-processing and data processing.

Data pre-processing

a) Geometric corrections

Before performing geometric corrections on ETM+, TM, and OLI Landsat images, it is necessary to determine the type of composite image to be used. A composite image combines bands with different spectral resolutions and the same spatial resolution on channels 1, 2, 3, 4, 5, and 7 with a spatial resolution of 30 meters. A composite image is created by entering data into the red, green, and blue (RGB) channels to obtain an optimal visual display to identify land use. The next step is to make geometric corrections to the RGB-543 composite image on the Topographic Map or Earth Map. Geometric correction is conducted by identifying Ground Control Points (GCP) on the original image and the topographic map. The value of the Root Mean Square (RMS) determines the accuracy of GCP (Lisnawati & Wibowo, 2007).

b) Image Cropping and Interpretation

Before the interpretation process, the image cropping process is carried out based on the research area boundaries using administrative boundary digital data (shp). The interpretation process is carried out by limiting areas with different interpretation element characteristics (Lisnawati & Wibowo, 2007).

Data Processing

Data processing consists of several stages, including the following:

a) Land Cover Classification (*Supervised Classfication)*

Image classification is crucial for obtaining land cover changes based on predefined land cover classes. Digital images are classified by utilizing the maximum likelihood method. The first step is to create a training area for each land cover category. Land cover classification uses Regions of Interest (ROI) as a representative for each different land cover so that the computer can recognize it based on its pixel value.

b) Land Use Change Analysis

Changes in land cover were analyzed by comparing maps of land cover changes from 2001 to 2020. Land cover is divided into four classes: built-up land, water bodies, vegetation, and agricultural area. Vegetation groups include shrubs and shrubs, primary and secondary forests, while agricultural land includes rice fields, fields, and plantations. Built-up land includes settlements, roads, airports, and mining. Finally, water bodies include lakes, reservoirs, ponds, swamps, and rivers.

c) Changes in Rainfall and Temperature Extremes

Extreme rain events were analyzed from IMERG data using the Expert Team on Climate Change Detection and Indices (ETCCDI) Index, as shown in Table 1. Furthermore, temperatures were analyzed from mean temperatures of EAR5 data during 2001-2020.

Table 1. List of the selected four extreme indices from ETCCDI used in this study

Category	Index	Definition	Unit
Precipitation-amount-based indices	R95p	Annual total precipitation when RR ≥ 95th percentile of wet days	mm
Precipitation-duration-based indices	CDD	Maximum number of consecutive days with precipitation ≤1 mm	day
Precipitation-duration-based indices	CWD	Maximum number of consecutive days with precipitation ≥1 mm	day
Precipitation-intensity-based indices	RX1day	Annual maximum 1-day precipitation	mm/day

Result and Discussion

Land cover change

Table 2 shows the land cover area for each land class for 2001, 2004, 2008, 2012, 2016, and 2020. The spatial distribution of cover changes can be seen in Figure 1. There was a change in land cover area in the four land cover classes in IKN in 6 years of observation. The downward trend occurred in the vegetation area, followed by increased built-up land and agricultural land in the IKN area. The most remarkable land cover change for the vegetation area occurred in 2004, around 6448.86 Ha, which turned into agricultural land, built-up land, and other areas. A significant decrease in vegetation area also occurred from 2012-2020. This resulted from forest fires in East Kalimantan in 2014 and 2019, where 64,207 hectares of forest area were lost to vacant land (Rosidah et al., 2021). In addition, some of the vegetated lands have been converted into agricultural land. Linear regression equation between the area of vegetation (y) and years (x) is given by y = -622.66x + 1E+06, R^2 = 0.89. Thus, there is a decrease in vegetation to 622 Ha/year.

The agricultural area also increased from 2012 to 2016. Linear regression equation between the area of agriculture (y) and years (x) is given by y = 2974.4x - 6E+06, R^2 = 0.87. Thus, there is an increase in agricultural area to 2974 Ha/year. This relates to land clearing for oil palm plantations from forest areas. In 2018, the area of oil palm in East Kalimantan reached 1,434,485 Ha, but in 2019, there was a decline in agricultural areas due to the forest fires. Changes of land cover caused by oil palm expansion are categorized into two types, concentrated and spotted (Dharmawan et al., 2020). Van der Laan et al (2018) found that the different types of land cover changes in east Kalimantan increased and involved more diverse and characteristic trajectories. Degradation to more open forest types was dominant. Deforestation to grasslands and shrubs reach ~17%, and to a lesser extent due to trajectories from forest to mining and agriculture reaching 11%. Kiswanto et al. (2018) also found the acceleration of land cover changes, with overall cover changes from natural forest to plantation forest and other cultivated land cover classes, and undeveloped shrublands.

The highest increase in the area of built-up land occurred in 2020. Linear regression equation between the area of built-up (y) and years (x) is given by $y = 356.52x - 713117$, $R^2 = 0.92$. Thus, there is an increase in the area of built-up land by around 356 Ha/year. The high rate of this increase is in line with the population increase, where East Kalimantan's population is increasing yearly. The total population in 2000 was 2,436,545 people, increasing to 2,840,874 people in 2005. This means that in that period, the population of East Kalimantan increased by more than 80,000 people yearly. In 2020 the population in East Kalimantan will be 3.77 million (Angi & Wiati, 2017) .

Although there is a decrease in the water body area, the area fluctuates yearly. Linear regression equation between the area of water body (y) and years (x) is given by $y = -32.148x + 65207$, $R^2 = 0.19$. If we look at this equation, the determinant coefficient is relatively weak, which indicates that the relationship between the area of the water body and the year is weak. However, a decrease of around 32 Ha/year was observed.

Table 2. Land cover change in IKN (Ha)

Year	Vegetation	Agriculture	Water body	Built-up Area
2001	44,519.94	7,227.72	546.57	932.49
2004	38,071.08	18,302.58	1,427.58	1,553.85
2008	36,600.30	12,191.40	339.39	1,766.16
2012	35,749.08	44,229.78	192.87	4,209.93
2016	32,188.95	58,204.80	990.09	4,842.09
2020	31,164.66	57,025.26	3.51	8,032.50

The high rate of land change in IKN will endanger the existence of forests in the area, even though in 2020, the relocation of the new capital city has not been carried out. If this change continues, it will lead to the loss of forest areas in East Kalimantan and IKN in particular. Using data from 1990 to 2009, Verstegen et al.(2019) projected that the closed-canopy forest can completely lose its typical patch size distribution by 2030 if unlimited development scenarios are dominant.

Relationship of land cover change with rainfall and temperature

Figure 3 shows the distribution of surface temperatures in the IKN area from ERA5 data. The highest temperature occurred in 2016 at 299.9 Kelvin. Meanwhile, the lowest average temperature occurred in 2008 at 298.9 K. Areas with a high amount of vegetation have lower temperatures than other areas. The relationship between land cover changes and the average temperature can be seen in Figure 4. The relationship between land cover changes and surface temperature, especially the vegetation area, is inversely proportional. The decrease in vegetation in 2012-2016 increased surface temperature. In 2016 with a vegetated land area of 32.188.95 Ha, the average surface temperature was 299.88 K. The highest built-up land area occurred in 2020, with an average temperature of 299.84 K. The lowest temperature occurred in 2001 when the change in vegetation was not very large. Linear regression equation between temperature (y) and vegetation area (x) is given by $y = -6E\text{-}05x + 301.49$ $R^2 = 0.66$. Thus, there is an increase in temperature when the vegetation area decreases.

The increase in the built-up area increases the surface temperature in the IKN area. Linear regression equation between temperature (y) and built-up area area (x) is given by $y = 0.0001x + 299.05$, $R^2 = 0.74$. Thus, there is an increase in temperature when the built-up area increase. The increase in agricultural land also causes an increase in surface temperature in IKN, with the regression equation $y = 1E\text{-}05x + 299.01$, $R^2 = 0.8074$. However, the water body did not show a significant relationship with temperature. The linear regression equation between temperature (y) and water body area (x) is given by $y = -7E\text{-}05x + 299.48$, $R^2 = 0.0141$. Thus, the increase in temperature due to an increase in the built-up area is the largest compared to other land use changes, which can be seen from the linear regression gradient value. This is related to the surface albedo. Changes in surface albedo are caused by changes in land cover types (Baroroh & Pangi, 2018). The imbalance of incoming and outgoing energy causes changes in surface temperature in the IKN area. This also causes an increase in temperature in IKN. Each surface receives the same solar radiation energy but with a different heat capacity, so the resulting temperature will also be different (Hermans, 2016). The spatial distribution of albedo for each land use, from lowest to highest, is forest, plantation, agriculture, shrubland, and built-up land. The spatial distribution of NDVI (Normalized difference vegetation index) and rainfall are inversely related to albedo. The relationship between rainfall and NDVI is directly and inversely proportional to albedo. This is related to the potential for the mass flow of moist air greater than the surface in areas of large vegetation, thereby increasing the potential for cloud formation and precipitation (Azizah, 2021).

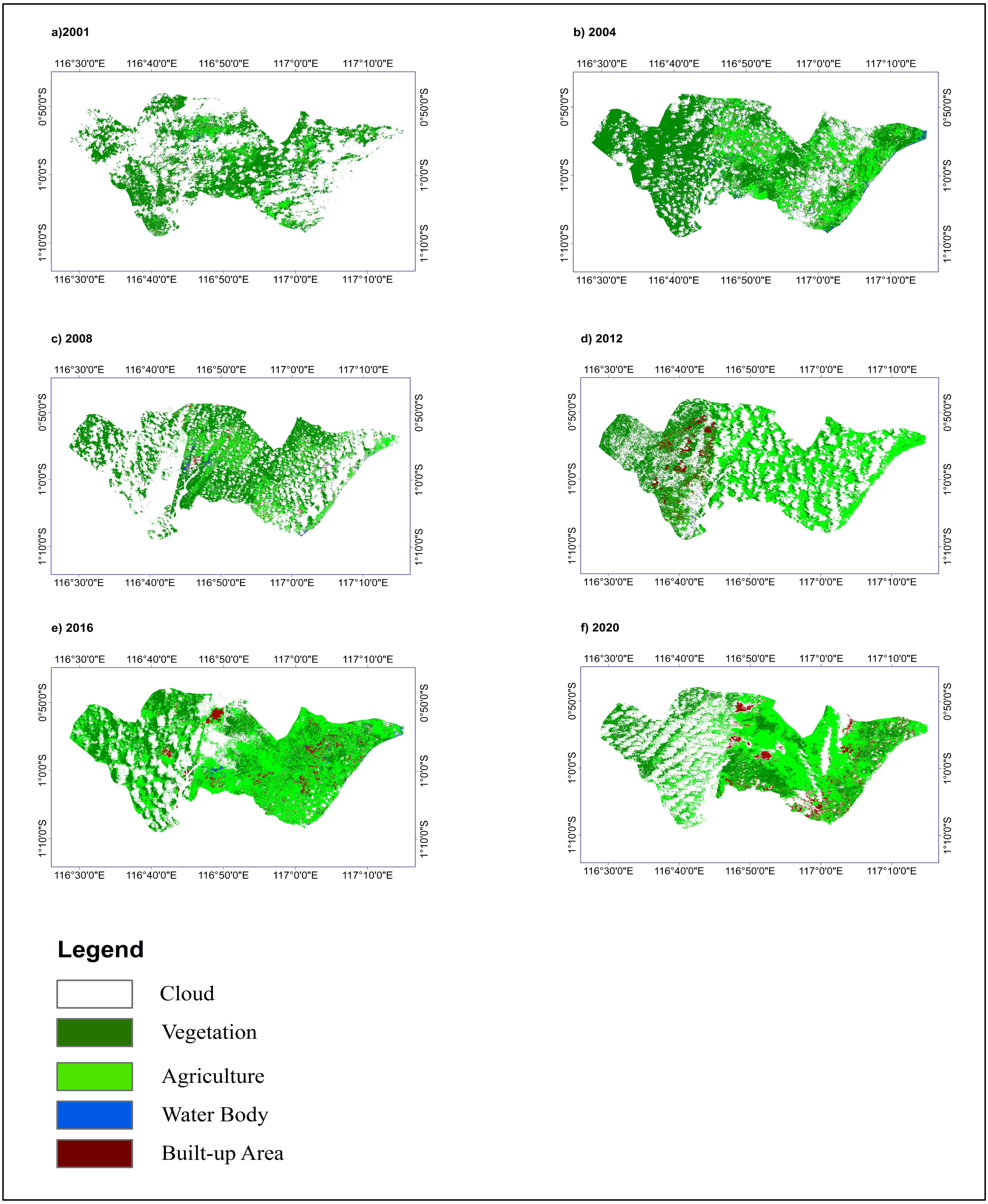

Figure 2. Map of land cover change in IKN area for (a) 2001, (b) 2004, (c) 2008, (d) 2012, (e) 2016, and (f) 2020.

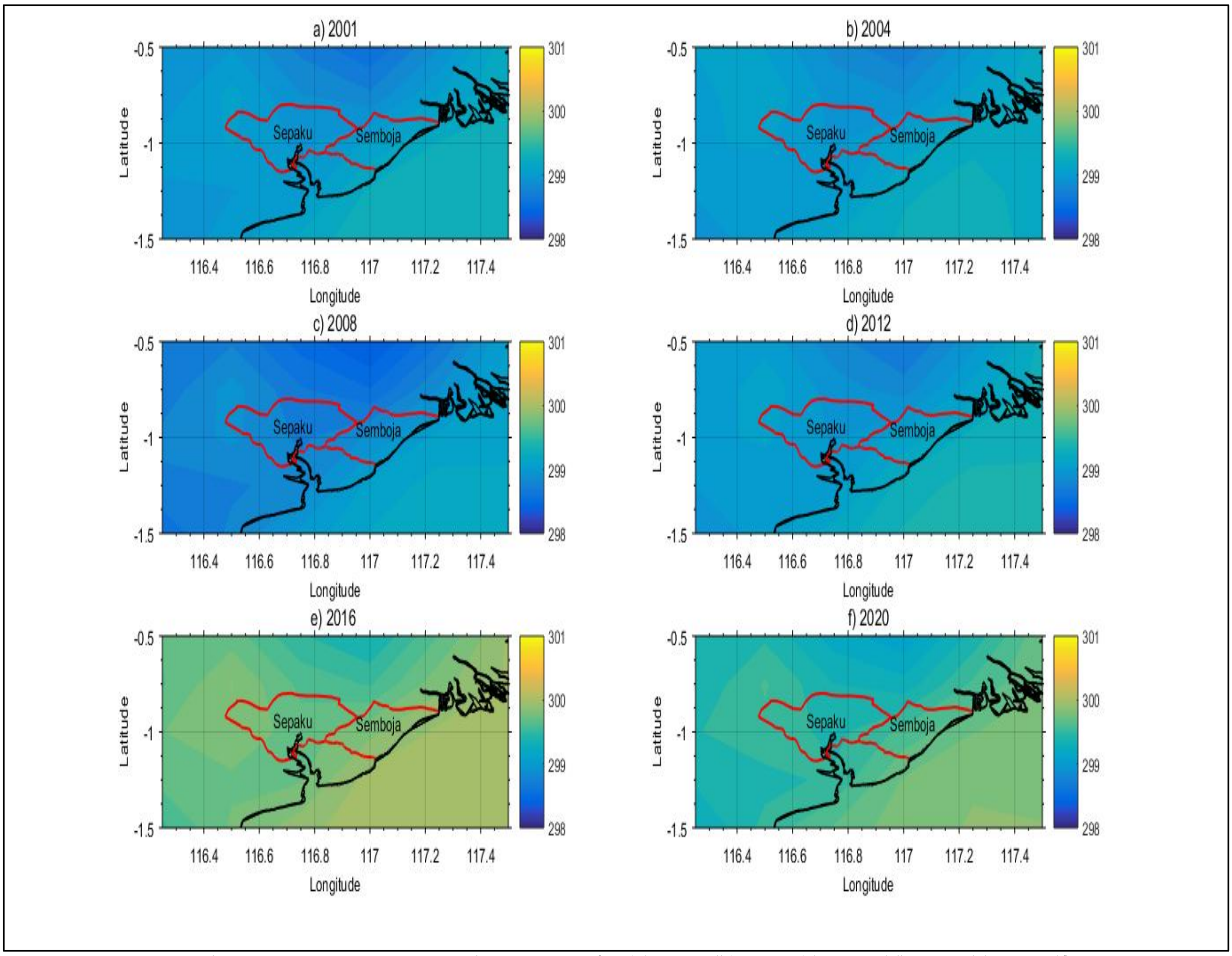

Figure 3. The average temperature in the IKN area for (a) 2001, (b) 2004, (c) 2008, (d) 2012, (e) 2016, (f) 2020

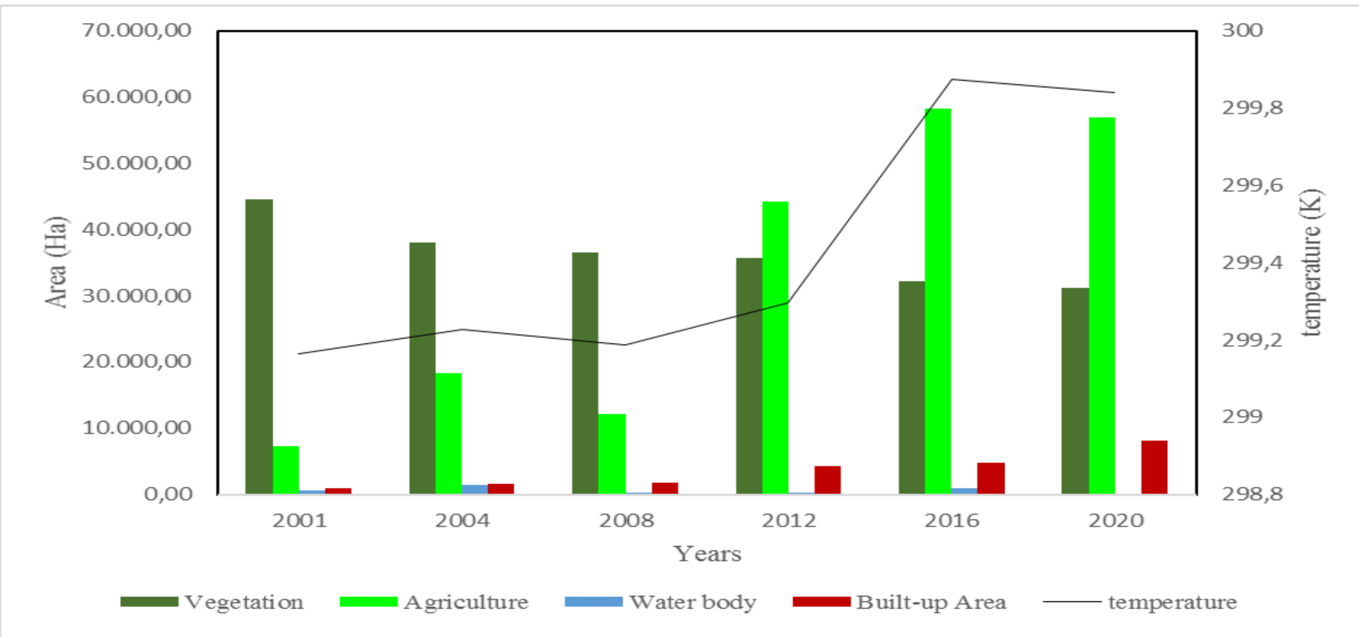

Figure 4. Relationship of land cover change with mean temperature.

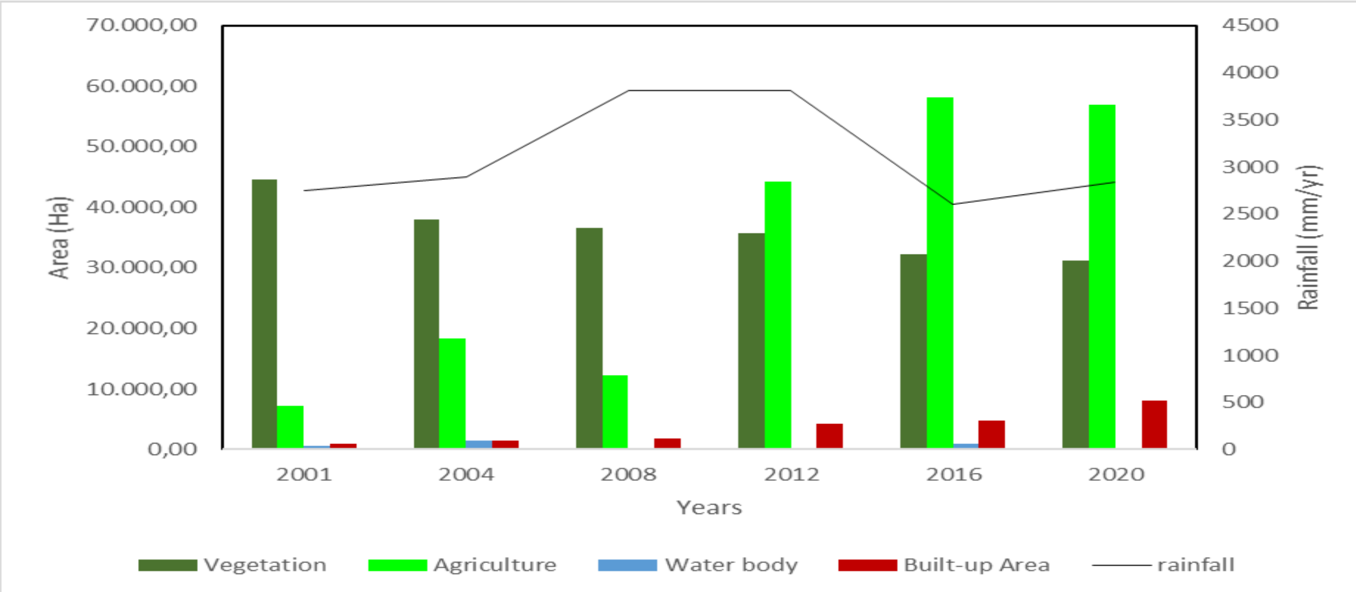

Figure 5. Relationship of land cover change with annual rainfall.

Figure 5 shows the annual rainfall in the IKN area. The highest rainfall occurred in 2012 and 2016, amounting to 3812.23 mm/year. In 2012, there was the highest increase in the built-up land area. The lowest rainfall occurred in 2016, at 2601.36 mm/year. Increasing agricultural land, build-up area, and water body lower surface temperature. The linear regression equation between rainfall (y) and each parameter (x) is given by $y = -0.0051\ x + 3283.6$, $R^2 = 0.0454$ (Agriculture area), $y = -0.4678x + 3390$, $R^2 = 0.2086$ (water body), $y = -0.035x + 3241.6$, $R^2 = 0.0296$ (Built-up area), and $y = -0.0007x + 3142.4$, $R^2 = 4E\text{-}05$ (vegetation). From this equation, it can be seen that the relationship between rainfall and land cover changes is not very significant. The water body shows a rather strong relationship because it is related to the rate of evaporation associated with the hydrological cycle. Vegetation also does not show a strong relationship with average rainfall.

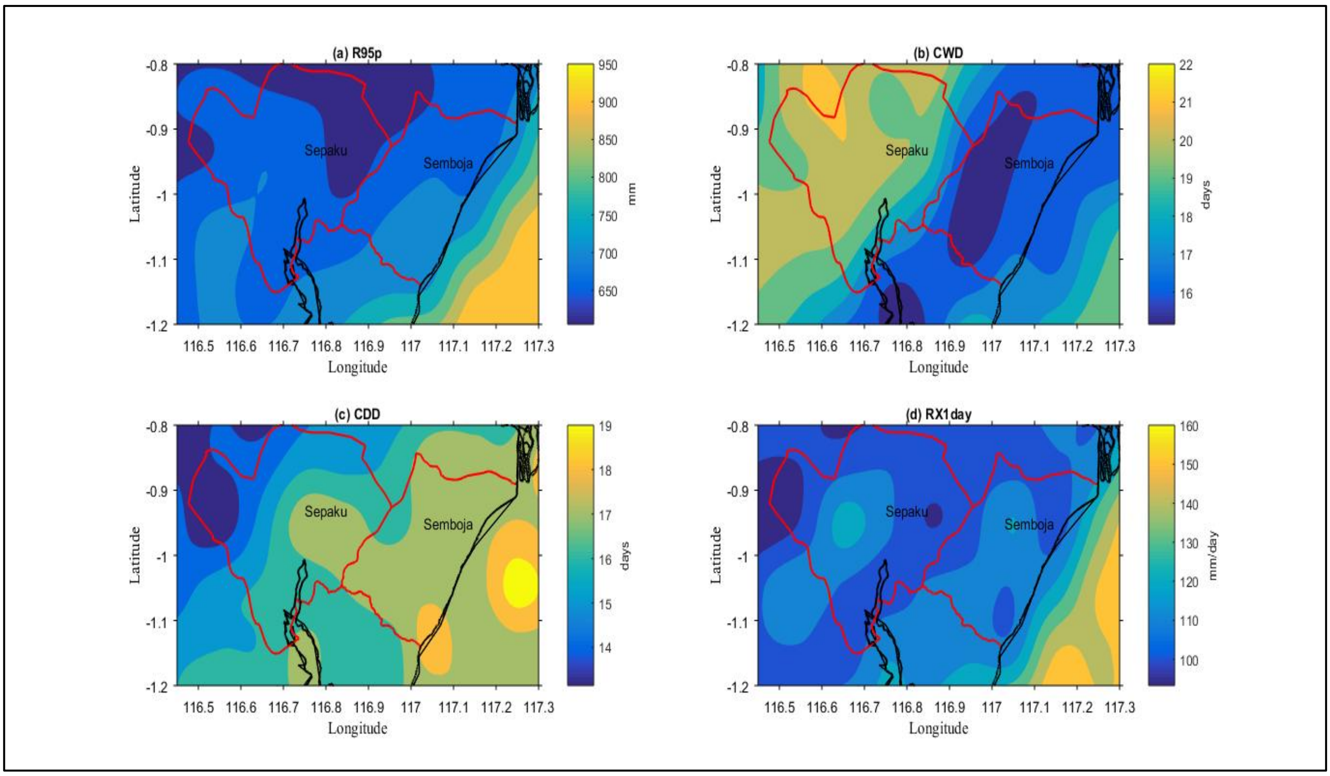

Figure 6. Spatial distribution of the mean of several extreme indices from IMERG data in IKN.

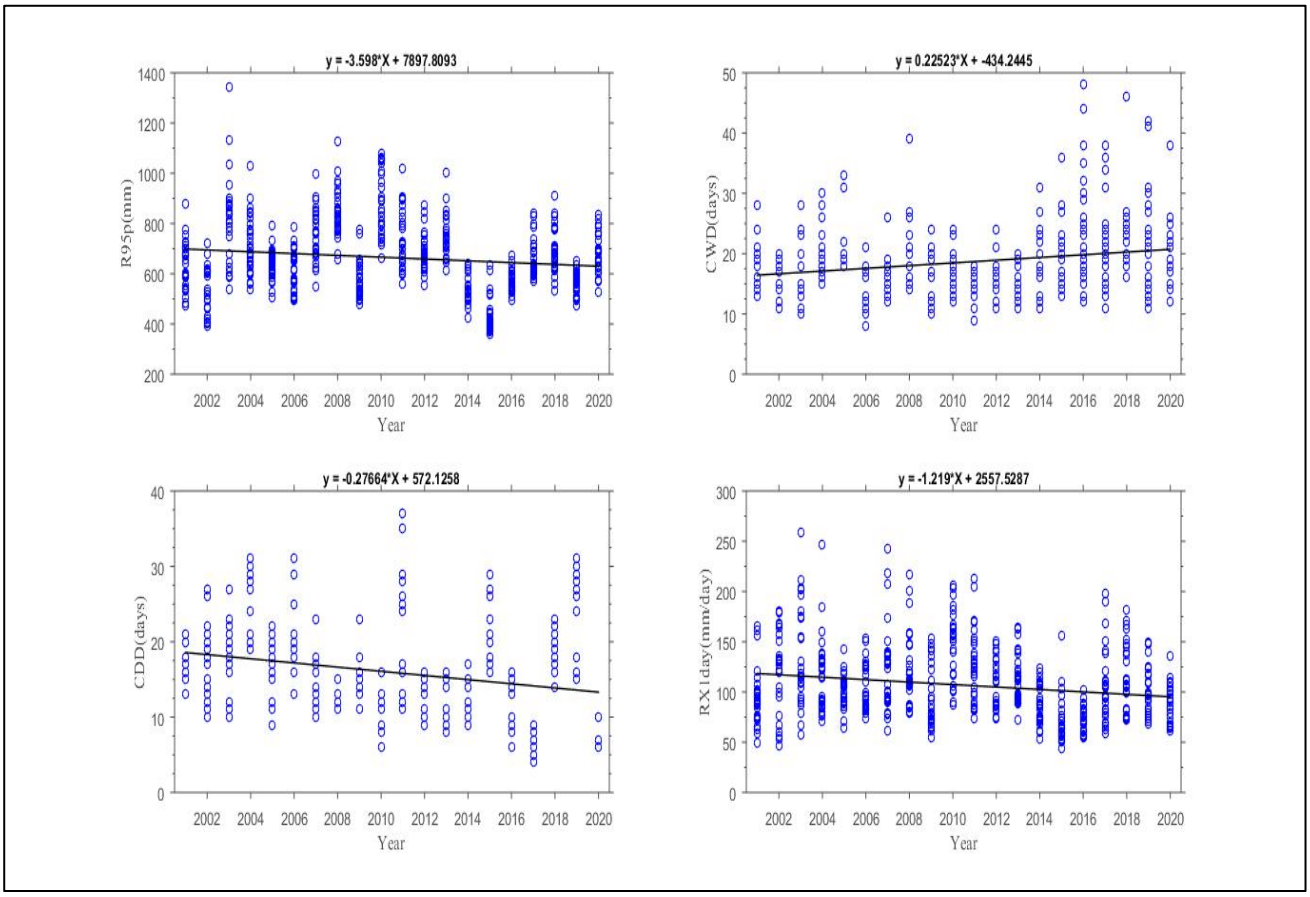

Figure 7. Trends in the extreme rain index from IMERG data on IKN during 2001-2020.

Figure 6 shows the spatial distribution of several extreme rain indices. R95P values in Sepaku and Semboja range from 650-700 mm. The CWD value is higher in Sepaku compared to Seboja and vice versa for CDD. This is related to the migration of rain from the ocean to the land and the topography (Ramadhan, et al., 2022a)

The extreme rain index value shows a decrease from 2001-2020, except for the CWD value, which shows an increase. This trend is in accordance with the annual and monthly indices obtained by Ramadhan et al. (2022a). This is consistent with a decrease in rainfall concerning land cover changes, as shown in Figure 5. However, the increase in CWD value needs to be a concern because consecutive rainfall extremes may cause more catastrophability than occasional extreme events.

Conclusion

This study shows a change in land cover in IKN from 2001 to 2020. The area of vegetated land is decreasing every year. Vegetation land is converted into built-up land, agricultural land, and water bodies. The decrease in vegetated land and the increase in built-up land agricultural land have caused an increase in surface temperature in IKN. The area of the water body more influences rainfall in IKN compared to other land covers. Most extreme rain indices showed a decline from 2001-2020, except for CWD, which showed a decline. This increase in CWD must be a concern in IKN development because consecutive precipitation extremes may cause more catastrophability than occasional extreme events and pose more serious threats to the safety of people's lives and property and the healthy development of a social economy. In addition, the high rate of change in vegetation land that occurs also needs to be a concern because if it is allowed to continue to decline, it will impact the climate in IKN.

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