Bulletin of Geology
e-ISSN 2580-0752

e-ISSN 2580 – 0752

Fakultas Ilmu dan Teknologi Kebumian
Institut Teknologi Bandung
www.buletingeologi.com

STUDY OF CLIMATE CHANGE HAZARDS USING THE CLIMATE HAZARD INDEX IN INDONESIA

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Abstract – Climate change is a serious problem for the world. It causes significant impact on ecosystems and people in all parts of the world's continents and oceans and poses grave risks to human health, global food security and economic development. One of the steps to reduce climate change disasters is climate risk management. Climate Risk Index (CRI) is a quantitative calculation of many climate risks with thresholds specific to extreme weather and climate events that cause disasters. One of the stages in preparing the CRI is to determine a hazard valuation or Climate Hazard Index (CHI). Because the climatic conditions in Indonesia vary with rainfall, it is necessary to conduct a study to determine the CHI associated with this variable. Therefore, in this study, climate hazards that are analyzed are limited to rainfall-related hazards, which are drought and extreme rainfall events. Then the constituent components of the CHI studied are the drought index and the extreme rain index. This hazard study shows an increasing trend in each of the CHI constituent component indices with a very high frequency of hazard events occurring frequently from 1995 to 2021. June was the month that had the highest average CHI among other months throughout 1962 -2021. In terms of spatial patterns, CHI is extreme in the Indonesian region with local and equatorial rainfall patterns. Whereas in the monsoon pattern, CHI is in the medium-very low range. Furthermore, CHI can be influenced by several factors, one of which is forest land cover. The results show that when the loss of forest land cover increases, the CHI value and its component index will also increase in the short term.

Key words: Hazard, Climate change, Climate Hazard Index, Indonesia

Sari *– Perubahan iklim merupakan permasalahan serius bagi dunia. Hal ini berdampak pada ekosistem dan manusia di seluruh bagian benua dan 1300ariabl di dunia serta berisiko besar bagi 1300ariable1300 manusia, keamanan pangan global, dan 1300ariable1300an ekonomi. Salah satu 1300ariabl untuk mengurangi bencana perubahan iklim dengan manajemen risiko iklim. Climate Risk Index (CRI) merupakan sebuah perhitungan kuantitatif banyak resiko iklim dengan threshold yang spesifik pada kejadian cuaca dan iklim ekstrim yang menyebabkan bencana. Salah satu tahapan penyusunan CRI adalah menetapkan valuasi bahaya atau Climate Hazard Index (CHI). Karena keadaan iklim di Indonesia bervariasi pada curah hujan, maka perlu ada kajian untuk menetapkan CHI yang berkaitan dengan 1300ariable tersebut. Pada kajian ini, bahaya iklim didefinisikan adalah bahaya yang berkaitan langsung dengan iklim di Indonesia, yaitu curah hujan. Kejadian bahaya yang dikaji adalah kekeringan dan hujan ekstrem. Maka komponen penyusun dari CHI yang dikaji adalah indeks kekeringan dan indeks hujan ekstrem. Kajian bahaya ini menunjukkan adanya kenaikan tren di setiap masing-masing indeks komponen penyusun CHI dengan frekuensi kejadian bahaya kategori sangat tinggi sering muncul sejak tahun 1995 hingga tahun 2021. Bulan Juni menjadi bulan yang memiliki rata-rata CHI tertinggi di antara bulan lainnya sepanjang tahun 1962–2021. Pada pola spasial, CHI ekstrem di wilayah Indonesia dengan pola hujan lokal dan ekuatorial. Sedangkan pada pola monsun, CHI berada dalam rentang sedang-sangat rendah. Selanjutnya CHI bisa dipengaruhi beberapa faktor, salah satunya dengan tutupan lahan hutan. Hasil menunjukkan bahwa ketika tutupan lahan hutan yang hilang meningkat, maka nilai CHI beserta indeks komponen penyusunnya akan meningkat pula dalam jangka waktu pendek.*

Kata kunci*: Bahaya, Perubahan iklim, Climate Hazard Index, Indonesia*

1. INTRODUCTION

Climate change is a serious problem that must be faced by the world (IPCC, 2023). This impacts ecosystems and people in all parts of the world's continents and oceans and poses grave risks to human health, global food security and economic development (Alexander 2006). Several years ago, many extreme weather and climate events were caused by climate change. Various disasters occur due to the effects of climate change such as floods, droughts, rainstorms, and so on (IPCC, 2012).

Meanwhile, the effects of climate change are difficult to predict (Zscheischler, 2018). The coming global climate change will increase climate uncertainty, which has many negative aspects in terms of economic and social development, productivity and quality of life, and the development, implementation, and realization of national objective strategies (Wang *et al.*, 2018).

Various efforts to deal with climate change have been made. Starting from the local community, institutions, government, even the United Nations. The problem of climate change also prompted the Earth Summit in Rio de Janeiro, Brazil 1992 which produced results United Nations Framework Convention on Climate Change (UNFCCC). The summit sparked other movements such as climate change campaigns, open discussions, and even policies on climate change. Not only making climate change policies, but climate risk management is needed. The goal of climate risk management is to reduce the negative impacts of climate on the environment, social life, and economy (Jones, 2014). For this reason, we need a calculation that can relate climate to these factors. In Indonesia, The Government of Indonesia (GoI) has seen climate change challenge as one of the most challenging factors, so GoI has prepared several national policies and plans to function as baseline for creating further adaptation planning at local level including provincial, municipality, and regency. (Salim *et al.*, 2012)

In terms of mitigating climate change, Climate Risk Index (CRI) is a quantitative calculation of one of the many hazard factors for climate change threshold specific to extreme weather and climate events that cause disasters and other losses in accordance with historical data (Wang *et al.*, 2018). CRI is an index that states the level of risk of extreme climate events either due to drought or extreme rain. CRI calculations in various places vary according to the disasters that are frequently hit. The CRI calculation consists of the hazard (hazard) and vulnerability (vulnerability) where the hazard in question is the potential for physical damage based on the frequency and intensity of a climate event and vulnerability is the condition affected by disaster hazard. One of the stages in preparing the CRI is to determine the hazard of using Climate Hazard Index (CHI). Because the climatic conditions in Indonesia vary with rainfall, it is necessary to conduct a study to determine the CHI associated with this variable.

Indonesia's climate is unique because it is caused by many things, such as being in the tropics and its territory in the form of islands with an interesting climate element to study in Indonesia, namely rainfall which can affect people's life patterns (BMKG, 2007). The potential for a disaster to occur in Indonesia is huge. Climate change in Indonesia will bring varied rainfall and will cause lots of floods (Vij, 2017). Many disasters are influenced by rainfall factors such as droughts, floods, landslides, erosion, and soon. In 2021, there were 15,336 floods, 6,664 landslides, 2,570 droughts, and 1,338 forest fires (BPS, 2022). These events can increase the risk of an area facing climate change disasters (Yusuf, 2009). Therefore, we need a parameter that can calculate the hazard from many of these disasters through the existing climate variables. (Eckstein, 2021)

2. DATA AND METHOD

2.1 Data

The data used in this study is ERA5 reanalysis data hourly averaged data on single levels. It is used to define the hazard for CHI. The data size has a resolution of 0.25° x 0.25° (~28 km x ~28 km) with hourly average variables in the period 1962-2021. The data is then processed into a monthly accumulation for each variable and according to the calculation of each index that will be used. In addition, there are several climate variables that must be adjusted to Indonesia's topography, such as vegetation and evapotranspiration. This data was chosen because of good climate variability and covers a large area so this data is suitable for calculating CRI values for Indonesia, which has a large area. Due to the diverse climate variability in Indonesia and limit on observation data availability, data reanalysis is the right choice.

Table 1. Research data

Data	Type	Variable

ERA5 hourly average data on single levels	Precipitation	Total Precipitation (m)
ERA5 land monthly averaged data on single levels	Land cover	Leaf Area Index (m^2/m^2)
	Evaporation	Total evaporation(m)

2.2 Method

Climate change refers to change in variable conditions such as temperature and rainfall over a long period of time. Changes in climate variability and extreme climate weather events have become a particular concern in recent years. Understanding changes in variability and climate extremes occurs due to interactions between changes in mean and variability (Meehl *et al*., 2007)

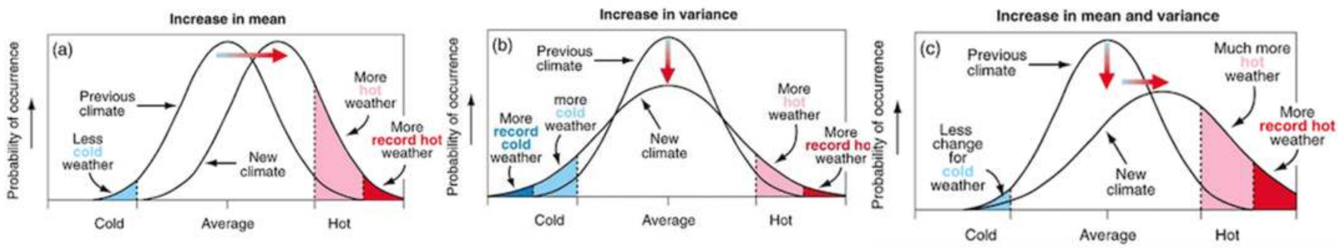


Figure 1. Schematic of extreme climate conditions (a) when the average increases, (b) when the variance increases, and (c) when both the average and variance increase (IPCC, 2007)

The method used in this study is the CHI calculation method for China (Wang *et al*., 2018) and adjusted for climatic conditions in Indonesia. This method includes the calculation of several indices, namely the drought index and the extreme rain index (Adams, 2017). After the index is calculated, the CHI value is calculated from several events each month. In addition, hazard in Indonesia mainly focus on rainfall because it is directly affected to climate change in Indonesia. In this study, disasters such as drought and extreme rain are disasters that are directly related to Indonesia's rainfall (Abrar, 2022). The entire index reviewed above is divided according to what is stated in **Table 3.**

Table 2. Hazard type and parameters

Danger type	Method	Parameter
Drought	Drought Index (Wang et al., 2007)	Rainfall, Evaporation, Vegetation Land Cover
Extreme Rain	Extreme Rain Index (Zhang et al., 2009)	Rainfall

Table 3. Index classification for CHI and its constituent indices (Wang, 2018)

Index Value	Information
0.00 – 0.20	Very low
0.21 – 0.40	Low
0.41 – 0.60	Mid
0.61 – 0.80	High
0.81 – 1.00	Very high

2.2.1 Drought Index

The calculation of the drought index has various calculations such as Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Precipitation Index (SPI), precipitation anomaly presentation, Palmer drought index, and so on. In this study, the index used to calculate the drought index (DI) was SPI (Wang et al., 2007) corrected for total evaporation and leaf area index. The drought index starts from calculating the monthly SPI (SPI_m) with the following formula:

$$SPI_m = \frac{x_i - \bar{x}}{s} \quad (1)$$

Where xi is the daily rainfall, $\bar{x}$ is the average daily rainfall, and s is the standard deviation of rainfall. The monthly rainfall value will be calculated using the module climate indices research with Python language (Adams, 2017). Then the SPI value itself is calculated based on several classifications to become a drought index (DI) with the formula:

$$DI = \begin{cases} 0, & SPI_m \geq -1 \\ SPI_m + 1, & -1{,}5 \leq SPI_m < -1 \\ 2 \text{ x } SPI_m + 2{,}5, & -2 \leq SPI_m < -1{,}5 \\ 3 \text{ x } SPI_m + 4{,}5, & SPI_m < -2 \end{cases} \quad (2)$$

$$MDI = \sum_{i=1}^{Day} DI_i \quad (3)$$

where MDI is the monthly drought index. Mark DI itself is still in daily form, so calculations are needed DI monthly, that is MDI calculated by equation 3. Then SPI is corrected with forest land cover data from leaf area index as follows:

$$X = \sum_{j=1} \alpha(MDI_j - Lf) \quad (4)$$

$$CMDI = \frac{(X - X_{min})}{(X_{max} - X_{min})} \quad (5)$$

Where MDI_j is the monthly drought index in the month j, Lf is *leaf area index* and α is a constant. It should be noted that the value of α is a constant for a month. According to research from Wang (2018), when there is a dry month, the constant can be adjusted according to the monthly rainfall value and the chance of drought occurring in that month. The probability of drought in the DJF season is small, so the constant value is 0.5. For other months it has a constant value of 1. Then after getting the value X which is the monthly drought index normalized to CMDI or *Climate Monthly Drought Index*. This index is used as a component in defining drought hazard for CHI values.

2.2.2 Extreme Rain Index

The extreme rain index calculation has various methods. For this study, the calculation method of the extreme rain index is derived from Wang's research modified for Indonesia. First of all, the total daily rainfall data is classified into several classes based on calculations from Zhang (2009) with a classification based on BMKG from several rain events in one extreme as follows

Table 4. Rainfall Rate (RR) Classification based on BMKG (2023)

RR (mm/day)	R_d
$RR < 50$	$R_d = 0$
$50 \leq RR < 100$	$R_d = \sqrt{n}$
$100 \leq RR < 150$	$R_d = 2\sqrt{n}$
$150 \leq RR$	$R_d = 3\sqrt{n}$

Where R_d is the index of daily extreme rainfall and n is the number of rainfall events according to classification in one day. After that, the monthly extreme rain index is calculated using the following formula:

$$R = \frac{\sum_{i=1}^{Day} R_{di}}{Day} \quad (6)$$

$$CMR = \frac{(R - R_{min})}{R_{max} - R_{min})} \quad (7)$$

Where R is the monthly extreme rainfall index, R_{min} is the minimum R over 1962-2021, and R_{max} is the maximum R during 1962-2021. Furthermore, the monthly extreme rain index is normalized in equation 7. Climate Monthly Rain (CMR) is used as an index value in defining the extreme rain hazard for the CHI component in Indonesia.

2.2.3 Climate Hazard Index for Indonesia

CHI for Indonesia is a calculation based on the drought index and extreme rain index. The CHI value for Indonesia is focused on disaster hazards that are directly related to rainfall, such as drought and extreme rain.

$$CHI_m = \sum_{i=1}^{N} D_{i,j} \tag{8}$$

Where N is the number of studied hazards and $D_{i,j}$ is the index value for disaster i in the j month. After these calculations, the CHI value is normalized so that the range of values can be classified from a CHI value of 0 to 1. CHI is a component of the climate disaster hazard in the CRI. There are at least two things that can be done after determining the CHI. After determining the CHI, research can be continued to determine the component of vulnerability in the CRI so that it can calculate the CRI. Meanwhile, CHI can also be projected into the future in the near, medium and far term. In this study, we mainly focus on calculating CHI for Indonesia in climate period (1962-2021).

3. RESULTS

3.1 Climate Change in Indonesia

Climate change in Indonesia is viewed from statistical changes from long variable data (Aldrian, 2011). Indonesia relies on the element of rainfall to determine climate patterns. Based on Normal Distribution in **Figure 1**, Indonesia is experiencing climate change marked by increasing mean and variance compared to the previous period. According to IPCC (2001), an increase in the average variable will increase the intensity of a variable and an increase in variance will increase the frequency of events. This situation resulted in the 1991 – 2021 period having high rainfall intensity with more frequency of rain events compared to the 1962 – 2021 period.

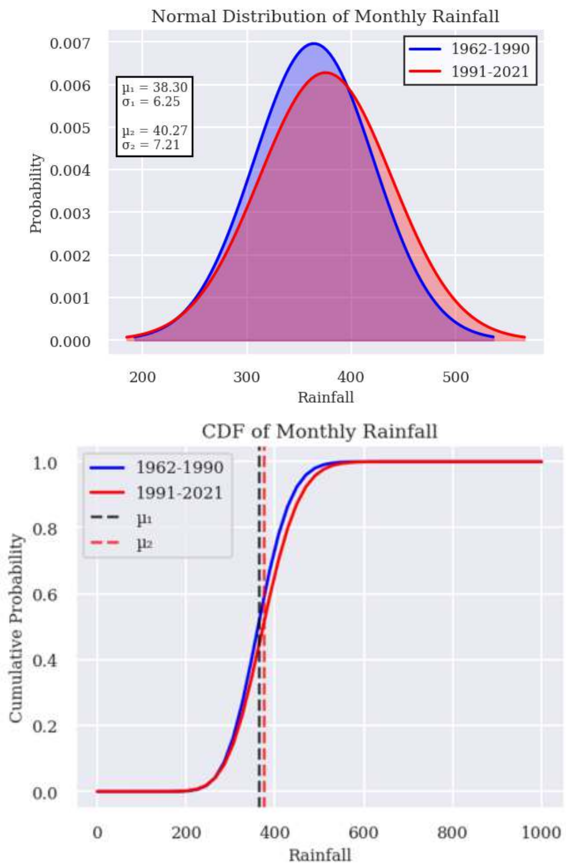


Figure 2. Normal distribution (top) and CDF distribution (bottom) for the period 1962–1990 then period 1991–2021.

On **Figure 2** shows the CDF distribution of Indonesia's monthly rainfall. CDF period 1990 – 2021 underestimate against the CDF for the period 1962 – 1990. This indicates that the CDF for the period 1990 – 2021 provides a lower probability estimate than the previous period. However, the CDF only looks at the probability of rainfall and does not directly indicate high intensity or frequency. If you review the averages on the CDF, it is clear that the 1991 – 2021 period is capable of producing higher intensity and frequency of rainfall events.

In addition to rainfall throughout Indonesia, the normal distribution of monsoonal, equatorial and local rainfall patterns for each region is also compared **Figure 3**. The results show an increase in the average rainfall in each region with a low cumulative probability estimate compared to the previous period. Meanwhile, the equatorial rainfall pattern area experienced an increase in variance compared to the previous period. This indicates that in each region the rainfall pattern in Indonesia is experiencing statistical climate change. These results indicate a statistical increase in extreme weather or climate events. The greater the variance and average of climate variables compared to the previous period, the greater the climate change experienced (Gaborit, 2022).

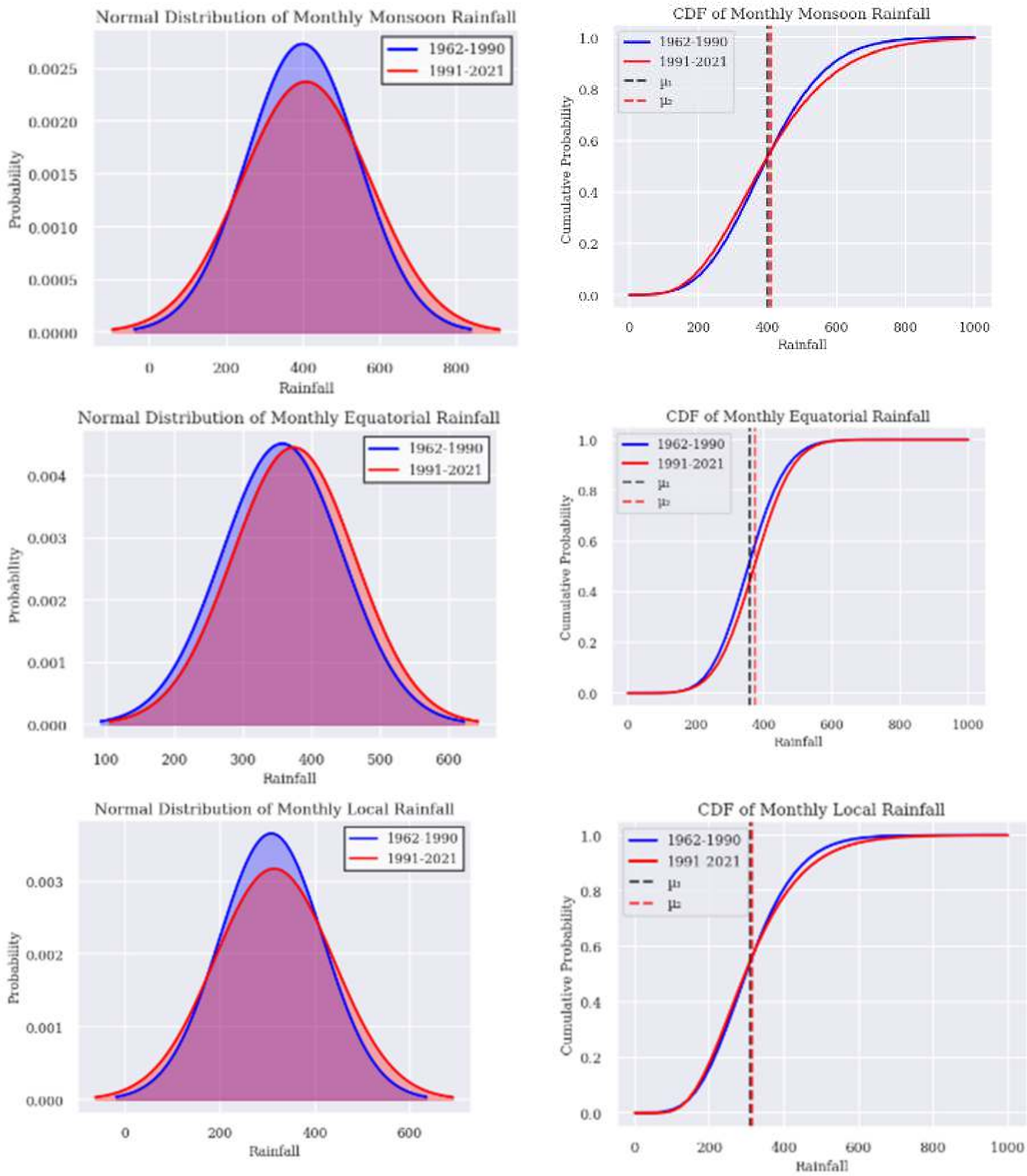


Figure 3. Plot of normal distribution and CDF distribution in 1962 period– 1990 then period 1991–2021 in each monsoonal (top), equatorial (mid), and local (bottom) area.

3.2 Drought Index

The average drought index shows an increasing trend from 1962 to 2021 **Figure 4**. The frequency of months that show a very high drought index often occurs after 1995. The highest drought index values occurred in August 1995 (1.00), August 2021 (0.98), June 2007 (0.97), August 2010 (0.96), and June 2020 (0.95).

We separate our data into four season periods; Rain season on period December-January-February (DJF), drought season on June-July-August (JJA) period, and two transition seasons on March-April-May (MAM) period and September-October-November (SON).

Figure 5 shows that the distribution of drought indices is different in several seasons. The JJA season became a season with a very high index category dominance. The MAM and SON seasons are seasons with a fairly equal distribution. Meanwhile, the DJF season has a very low drought index in the spatial plot. This is because Indonesia has a dominance of monsoonal rainfall patterns so that the drought index rarely reaches very high or high during the DJF season. The highest average drought index each season is in Indonesian regions such as the west coast of Sumatra, Sulawesi, the Maluku Islands and parts of Papua Island.

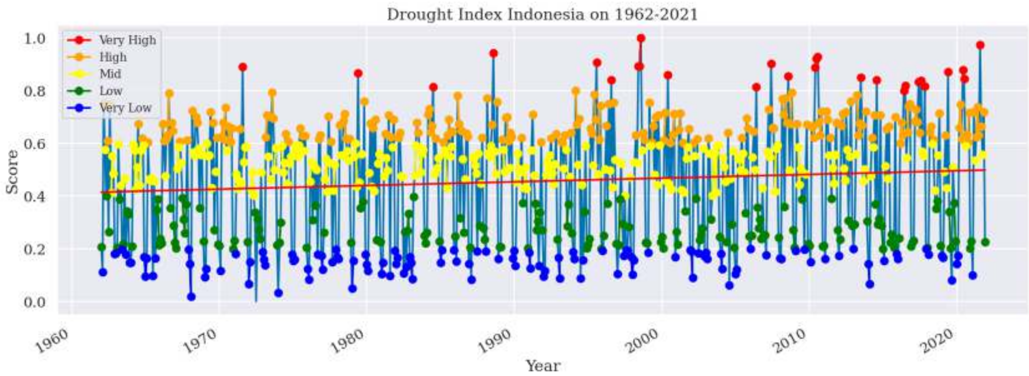


Figure 4. The average Indonesian drought index 1962 – 2021

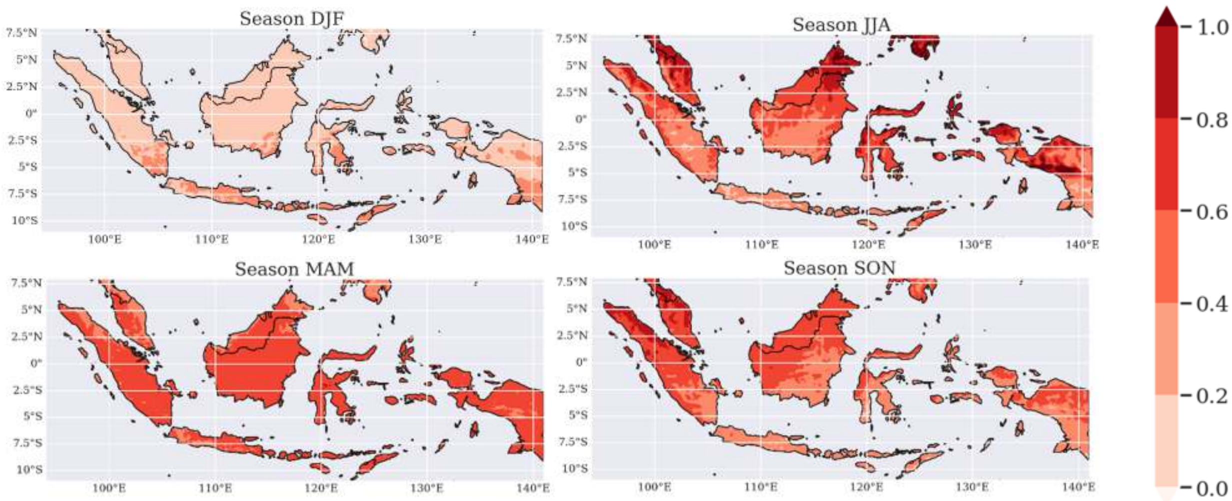


Figure 5. Map of the average drought index of Indonesia 1962 – 2021 with four successive different seasons, namely DJF (a), JJA (b), MAM (c), and SON (d).

3.3 Extreme Rain Index

Figure 6 shows the temporal extreme rain index, there is a trend of the extreme rain index in the low and very low categories ranging from 0 to 0.4. This is because extreme rain events are rare and the scale is not wide. The extreme rain index reached the very high category in July 2013 (1.00), June 2020 (0.96), June 2017 (0.92), and July 1995 (0.90).

The distribution of the maximum extreme rain index is in June and July. Even though Indonesia is in a dry season, it is possible that extreme rain events will occur. On **figure 7** shows a spatial map of the maximum rainfall in Indonesia with the highest extreme rain index around Papua. The index in the medium-very high range is found in the central part of Papua and parts of the northwestern coast of Sumatra. This is in accordance with a study conducted by (Hamada, 2002) where the rainfall obtained in the area each year can be more than 3000 mm.

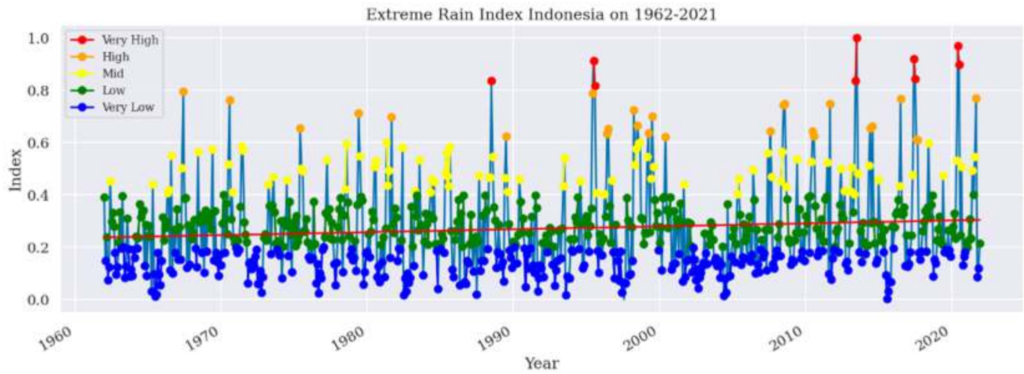


Figure 5. The average extreme rain index for Indonesia 1962 – 2021

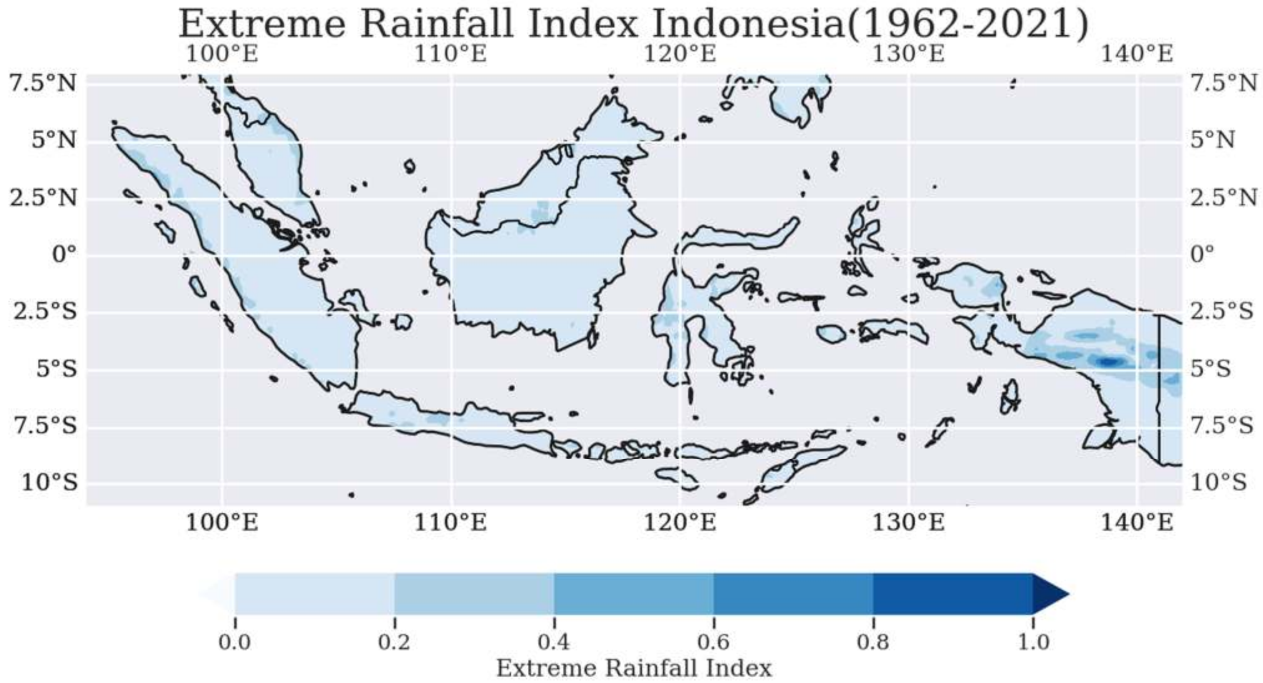


Figure 7. Maximum Extreme Rainfall Index in Indonesia (1962 – 2021).

3.4 Climate Hazard Index Indonesia

The CHI for Indonesia consists of components of the drought index and extreme rain index in Indonesia. CHI temporal mean plot results at **Figure 7** shows an increasing CHI trend throughout 1962 – 2021. This is because the components of the CHI, namely the drought index and the extreme rain index, have an equally increasing trend. The frequency of months with very high CHI categories increased after 1995, such as in June 2020 (1.00), June 2017 (0.94), and June 1979 (0.85).

On **Figure 8** shows the monthly distribution of Indonesia's CHI 1962 – 2021. CHI is maximum in June, followed by July and August. However, on average, the months of March, April, June and November are the highest CHI averages compared to other months. This indicates that climate hazard events often occur in that month. Next, on **figure 10** is a map of the average CHI of Indonesia from 1962 to 2021. The results show that several regions of Indonesia have a very high CHI category, such as parts of the islands of Sumatra, Java, Kalimantan, Sulawesi, Nusa Tenggara, Maluku, and Papua. There are areas with very low moderate CHI categories on the island of Java and several areas in Papua.

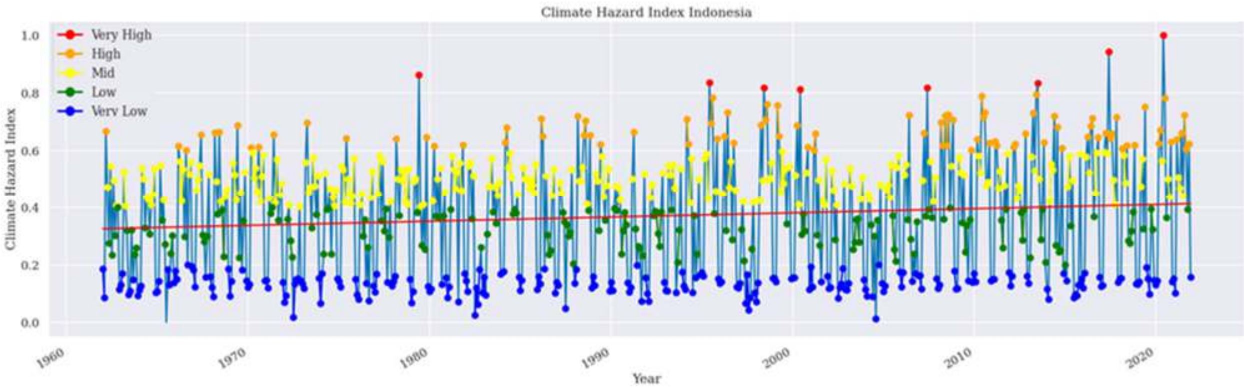


Figure 8. temporal plot of CHI Indonesia 1962 – 2021 with the red line is the CHI trend.

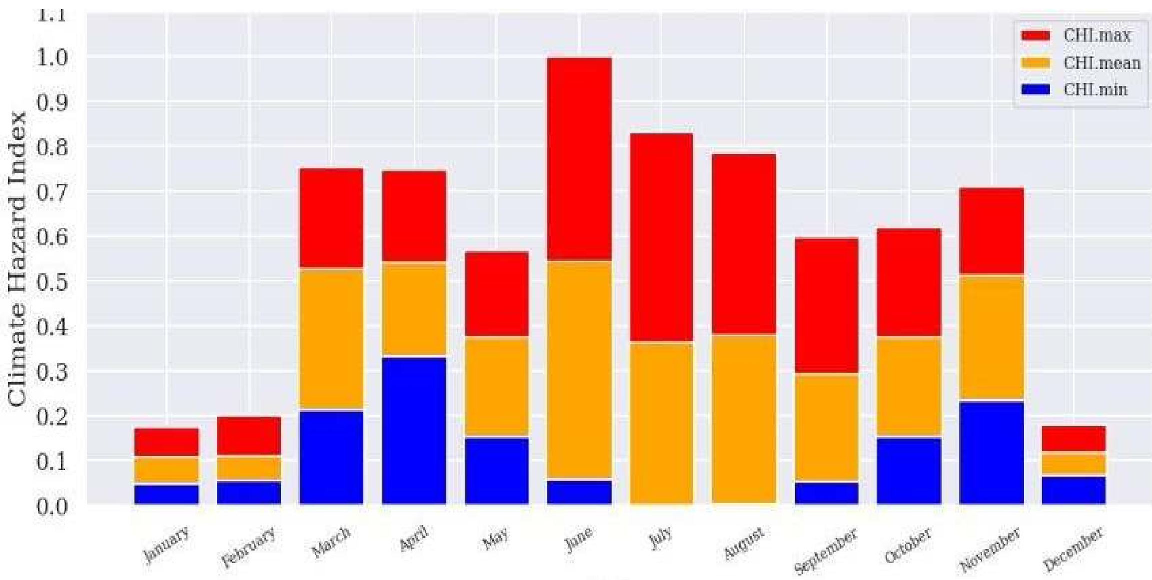


Figure 9. The CHI value is reviewed from the average, maximum, and minimum CHI monthly for Indonesia 1962 – 2021.

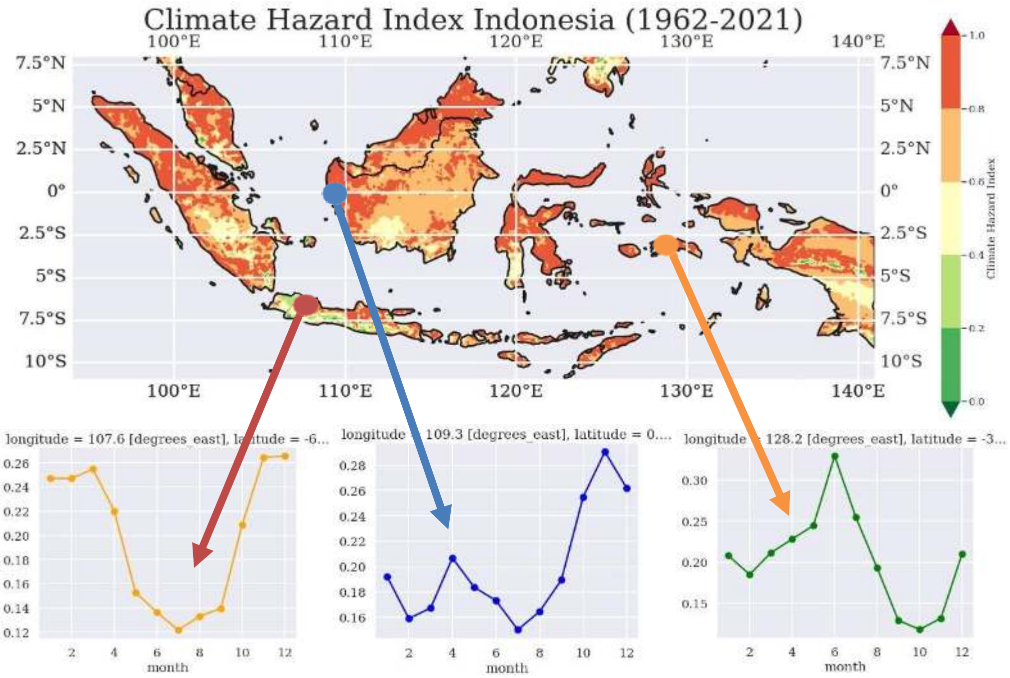
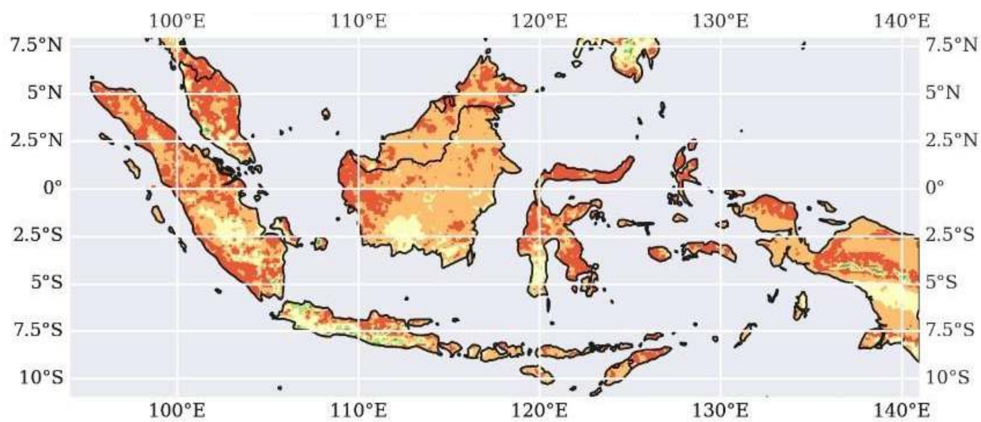


Figure 10. Accumulation map *Climate Hazard Index* (CHI) Indonesia 1962 – 2021 (top) with monthly CHI consecutively (bottom) in the monsoonal (left), equatorial (middle), and local (right) pattern graphs.

Then areas with extreme CHI values are concentrated in provinces with equatorial and local rainfall patterns such as Sulawesi, Papua, Maluku and Aceh. Meanwhile, regions in Indonesia with moderate to very low categories are concentrated in areas with a monsoonal pattern, such as Java Island, parts of Sumatra, South Kalimantan, South Sulawesi and the southern part of Papua. Because the CHI value is low, the climate change hazard is not as great as areas with high CHI values that allow it to be inhabited throughout the year. This is one of the reasons for living in an area with minimal climate hazards.

On **Figure 10**, there is a graph of the average CHI with monsoonal, equatorial, and local patterns. Points were taken from Palembang City, Pontianak City, and Ambon City. The largest average CHI was in Ambon City in June, which was 0.34. Furthermore, the highest maximum CHI in Indonesia is in Gorontalo, precisely in Bone Bolango Regency. Then followed by Mamuju Regency (West Sulawesi) and Nabire Regency (Papua). The three regions have local rainfall pattern.



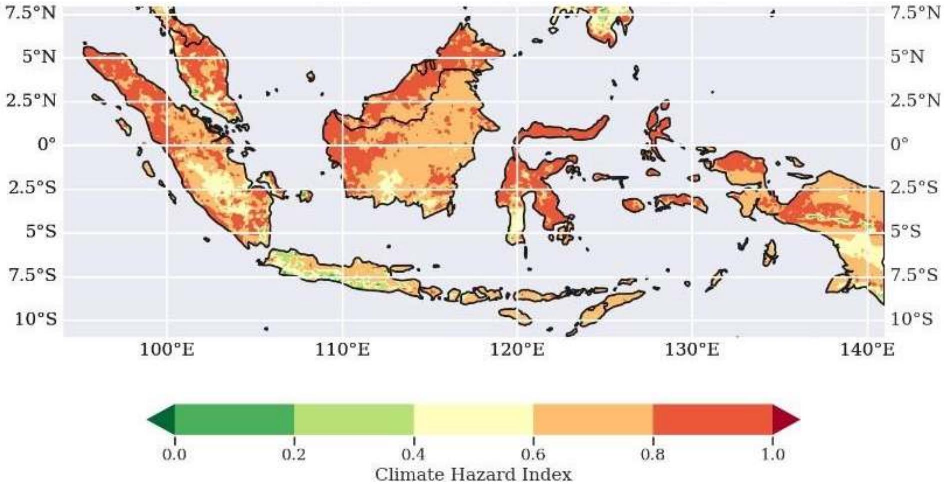


Figure 11. Indonesia CHI on 1990 average map (top) and Indonesia CHI average map on 2021(bottom).

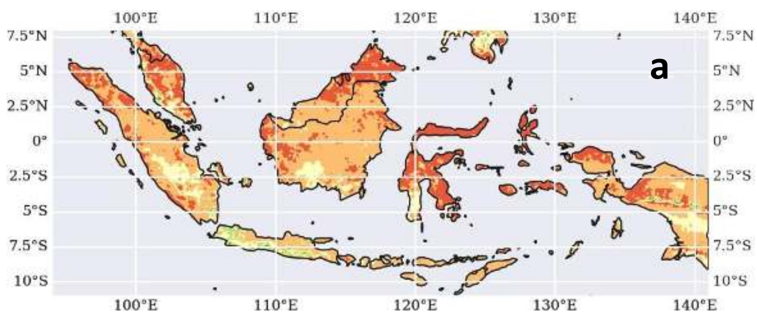
On **Figure 11**, a map of Indonesia's average CHI in 1990 compared to 2021. It appears that there has been an increase in CHI from moderate to high levels in several regions of Indonesia such as northern Sumatra, western Kalimantan, Sulawesi, and the Maluku Islands. The increase in the area of CHI was triggered by climate change in Indonesia which resulted in an increase in rainfall intensity and an increase in the frequency of rainfall events in Indonesia.

4. DISCUSSION

4.1 Comparison of CHI with IRBI 2021 Hazard Map

In the IRBI 2021 book written by Asfirmanto (2021), there is a disaster hazard map for Indonesia in 2021 on **Figure 12b** and multi-risk disaster region based in Indonesia on **Figure 12c**. There are similarities with the 2021 CHI Indonesia map on **Figure 12a**, namely the high level of danger is in the eastern part of Indonesia that cover Sulawesi and Papua Island, to be precise around the waters of eastern Indonesia such as the Maluku Islands, Sulawesi and Papua. It should be remembered that the BNPB output map has a multi-disaster hazard index assessment such as tsunamis, earthquakes, volcanic eruptions, floods and other disasters. While the CHI assessment is based on two hazards, namely drought and extreme rain. But this is interesting because there are similarities to the map from IRBI. This indicates that the territorial waters of eastern Indonesia have a high level of danger, even though the type of hazard is different.

While hazard in IRBI 2021 nearly same with our study, we cannot justify our study to be compared with risk on **Figure 12c** because there is vulnerability and capacity calculation on this part. Even thought, we put our suggestions to continue our study for calculating vulnerability and capacity as part of risk calculation. But, our CHI accumulation in 2021 nearly same with multi-risk map. We have to find more about this assessment in the future work.



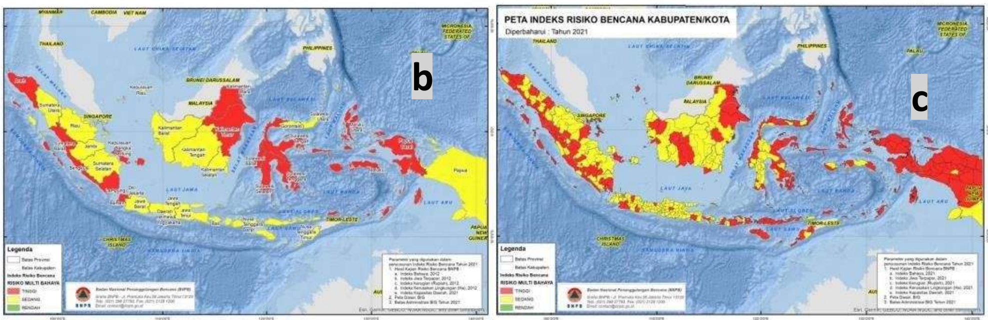


Figure 12. Average CHI Indonesia in 2021(a) with multi-hazard disaster map province based in 2021 (b) and multi-risk disaster map region based in 2021(c) from IRBI 2021 (Asfirmanto, 2021).

4.2 Effect of Climate Hazard Index

We discover our study to find any factors of increasing or decreasing CHI. One that can affect CHI is forest cover and land. The forest acts as a water vapor retainer so that rain does not occur frequently. However, when the forest land cover is lost, evaporation will occur and the frequency of
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rain will increase. The role of the forest is also as a temporary water reservoir, so that when there is a drought, one of the water reserves is in the forest so that drought hazard events can be prevented. When an area experiences rain, the forest can store rainwater as a water reserve if there is a drought in the future.

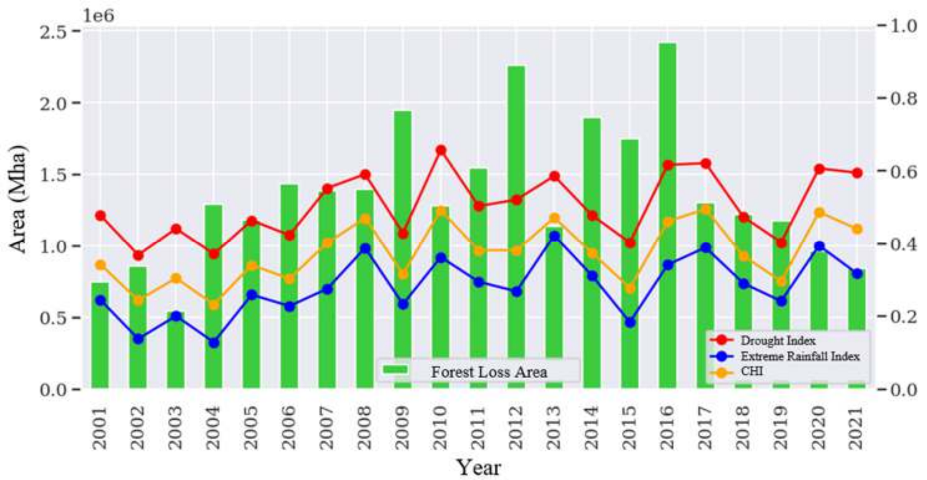

Figure 13. Forest land loss graph from *Global Forest Watch* (2021) with Indonesia's CHI for 2001 – 2021. The red line is the drought index, the blue line is the extreme rain index, and the orange line is the CHI for Indonesia.

Based on forest land cover data from *Global Forest Watch* (2023), Indonesia from 2001 to 2021 has experienced loss of forest land cover in several areas due to deforestation. On **Figure 13** is a graph of forest land cover loss with CHI and its component indices during 2001 – 2021. When forest land cover loss increases, CHI will also
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increase in subsequent years such as in 2003 – 2004, 2009 – 2010, 2011 – 2012, 2016, and in 2019. Something unique happened in 2012 when Indonesia lost a large forest area. In 2013, the extreme rain index increased dramatically to almost match the CHI in that year.

5. CONCLUSION

Based on the results and discussions that have been carried out regarding Indonesia's Climate Hazard Index 1962 – 2021, the following conclusions are drawn:

- CHI in Indonesia is restricted from danger/hazard related to rainfall, namely drought and extreme rain. The CHI value is high when the index component obtained by an area has a high index component.
- Areas that have extreme CHI are concentrated in the eastern part of Indonesia, especially in areas that have local and equatorial rainfall patterns. Meanwhile, areas that have a minimum CHI are concentrated in areas of Indonesia that have monsoon rain patterns.
- One of the reasons for the increase in the CHI value is the loss of forest land cover or land changes that remove water catchment areas. Related index variations of one of the same variables will influence each other even though they are opposite in nature.

6. SUGESTIONS

There are several suggestions for further research, including the following:

- This study is still in progress in science basic analysis, so that this study has the potential to be projected into the future such as 2030 – 2060 and so on.
- The CHI component can be added with indexes related to Indonesia's climate such as winds, storms, and others. But there needs to be a deeper study if you want to add to the index. It is also possible to use an index other than that used in this study in defining hazard.
- Once the hazard has been defined, the risk can be calculated by adding the vulnerability and capacity indices to yield a climate risk index for Indonesia.

ACKNOWLEDGMENT

The Author grateful to Implemented Meteorology Laboratory ITB as provide our work, which support to our model python script building. We are grateful for the comments and suggestions made by the anonymous reviewers. Data are available on ECMWF ERA-5 website on https://climate.copernicus.eu/ and method of our work can be access by request.

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