Analysis of key locations as indicators for extreme climate impacts in supporting climate change adaptation in Indonesia

W Estiningtyas\textsuperscript{1,4}, H Syahbuddin\textsuperscript{2}, Harmanto\textsuperscript{1}, A Pramudia\textsuperscript{1} and S K Dermorendo\textsuperscript{3}

\textsuperscript{1}Indonesian Agroclimate and Hidrology Research Institute, Jl. Tentara Pelajar No 1A Cimanggu Bogor 16111, Indonesia
\textsuperscript{2}Indonesian Agricultural Research and Development Agency, Jl. Raya Ragunan No. 29, Pasar Minggu, Jakarta Selatan 12540, Indonesia
\textsuperscript{3}Indonesian Center for Agriculture Socio Economic and Policy Studies
\textsuperscript{4}Corresponding author: woroestiningtyas08@gmail.com

Abstract. Indonesia has a large tropical archipelago with a complex and dynamic climate. Climate change has a significant impact especially in the agriculture sector where the magnitude of such impact varies from one location to another. Information about the magnitude of the impact and its monitoring in each location is still limited. The research objective was to determine the key locations for Indonesia’s climate variability based on SST Niño 3.4 index in El-Niño and La-Niña conditions. More than 4000 rain-stations data were used in this analysis. Key locations were determined based on a strong and significant correlation between rainfall and SST Niño 3.4 index under El-Niño and La-Niña conditions with a lag of 1 to 4 months. Based on the analysis results, 6 rain stations could be used as key locations on El-Niño and 5 rain stations on La-Nina condition. Key locations can be used as priority locations for impact analysis and monitoring of the impact of extreme climate, especially in the agricultural sector.

1. Introduction
Indonesia is one of the largest archipelagic countries in the world. The number of islands in Indonesia is around 17504 [1]. Indonesia's geographic position which is flanked by two oceans (Indian and Pacific) and two continents (Asia and Australia) makes Indonesia’s climate very complex and dynamic because it involves several global cycles in both the atmosphere and the oceans. Although there are only two seasons (rainy and dry season), the distribution and intensity of rainfall in Indonesia varies widely. In general, Indonesia is divided into 3 rain patterns, namely monsoonal, equatorial and local [2].

The extreme climate events of El-Niño and La-Niña are some of the parts and forms of climate change that occur most frequently and have quite a wide impact. Rainfall is a climate parameter with a clear impact due to extreme climatic events like El-Niño and La-Niña. Rainfall is closely related to global processes that can be studied through Sea Surface Temperature Anomalies (SSTA) indices such as Niño 3.4. According to NCAR [3], the Niño 3.4 index is the index most commonly used to define El-Niño and La-Niña. SST Niño 3.4 is observed in the Pacific Ocean in the region (5°N – 5°S, 120°–170°W) [4]. The results of the research [5,6,7,8] showed a close relationship between rainfall and Sea surface Temperature Anomaly (SSTA) Niño 3.4. Naylor [8] succeeded in measuring the relationship between SST, rainfall, and rice production in Indonesia over the last three decades, where there is a very strong relationship, especially in Java, which is the centre of food production (55%). The results of
this study can be used as a basis for determining whether the rainfall in a location has a strong and significant correlation with Sea Surface Temperature (SST) Niño 3.4.

The extreme climatic events El-Niño and La-Niña which are the indicators of climate change are phenomena that have a fairly wide impact in almost all sectors. The agricultural sector is one that has been significantly affected, especially the food crops sub-sector [9]. The biggest impact of climate change on the agriculture sector is heavily affecting the production [10,11,12,13,14,15,16,17,18]. SST Niño 3.4 variability affects 50% rainfall variation in Indonesia [5]. An increase of 1°C SST Niño 3.4 on average July-September can reduce rice production by 3.7% on irrigated land and 13.7% on rainfed land in the dry season [7]. Floods and drought are the most frequent impacts due to extreme climate El-Niño and La-Niña which cause rice yield losses in the Brantas watershed of East Java of 5.2 tons [19]. The extreme climate events of El-Niño and La-Niña are often recognized as occurring after their effects are felt. Anticipatory action is still very limited due to the lack of data and information on priority locations for impact analysis and monitoring.

The impact of extreme climate events is different at each location. Areas that are highly vulnerable to climate change will receive a greater impact than those less vulnerable ones. Due to the large areas in Indonesia and the different impacts of climate change in each region, it is necessary to have key locations. A key location is a location where the rainfall in that location has a strong and significant correlation with global phenomena so that it can be used for assessment of the impact of extreme climate and monitoring in order to anticipate and minimize risks. Key locations are locations that can be used as indicators to determine the magnitude of the impact of extreme climate events, especially on the agricultural sector which is the most significantly affected by climate extremes and change. If it is known that there are indications that extreme climates will occur, then key locations can be used to monitor their impact, especially on the agricultural sector.

The purpose of this paper is to determine the key locations for Indonesia’s climate variability based on SST Niño 3.4 index in El-Niño and La-Niña conditions. The availability of information on the distribution of key locations for Indonesia’s climate variability is expected to assist policymakers in determining priority locations to determine the magnitude of the impact and monitoring it so that an action program can be developed in the context of adaptation to climate change.

2. Materials and method
The data used in the analysis include monthly rainfall data with a period of more than 20 years and SST Niño 3.4 data sourced from NOAA [20]. Based on monthly rainfall data from all rain stations in Indonesia, data selection was carried out by selecting a data period of more than 20 years with the consideration that this period was sufficient to see extreme climate events, while dates that vary according to the completeness of the data at each rain station. Among the 4868 rain stations whose data were used, after the selection process, 1167 rain stations had eligible data. Rainfall data and SST Niño 3.4 index data were then analysed to determine the level of correlation and significance. The correlation values selected were strong and very strong (>0.5 or <-0.5), while the value of significance was selected as significant and highly significant (α <0.1). The level of significance (p or α) expressed as a proportion or percentage in this analysis was with a confidence level of 90%.

Key locations were determined by selecting rain stations which had strong positive and negative correlations and significant. The key location was a location where the rainfall anomaly in that location was strongly influenced by the global index anomaly where this global index was an indicator of extreme climate. Therefore, key locations were important as locations for assessment of the impact of extreme climate and monitoring in the agricultural sector. The selected location was then mapped. The step of analysis was presented in Figure 1.
3. Results and discussion

The results of the correlation analysis between rainfall anomalies and SSTA Niño 3.4 in El-Niño conditions show that 6 key locations have a strong and significant correlation at a lag of 1 to 4 months (Figure 2). Each location provides a strong and significant correlation at different or the same lag. One station can produce a strong and significant correlation on more than 1 lag. Lag illustrates that rainfall does not happen immediately at the same time, but it takes time in the process of atmospheric dynamics for the next 1 to 4 months. The time required for the formation of rain in a location varies. Based on the research results conducted in Indonesia, the lag of 1 to 4 months still produces a strong correlation [21,22]. For example, the Class III Meteorological Station Moanamani, Dogiyai District, Papua Province, where lags 2, 3, and 4 produce a strong correlation value (more than 0.5). This means that the current rainfall in Moanamani and its surroundings is closely related to SST Niño 3.4 in lag 2, 3, and 4 months ago. Likewise in the Noling Watershed, Luwu Regency, South Sulawesi Province in lag 2 and 3 (Table 1).

The distribution of key locations is classified into 3 categories: "strongly negative correlation which is assigned as very significant", then "strongly positive correlation- which is assigned as significant" and "strongly positive correlation-very which is assigned as significant". Besides, the strongly negative correlation classification is assigned as very significant in 1 location like Tannah Grogot, Paser District, East Kalimantan Province. The strongly positive correlation-significant is assigned in 1 location, namely Roya Park, Jenepondo District, South Sulawesi Province. The strongly positive correlation is assigned as very significant has 4 locations, namely Nglipar (Gunung Kidul District, Yogyakarta Province), Muara Teweh Tengah (North Barito District, Central Kalimantan Province), Moanamani Class III Meteorological Station (Dogiyai district, Papua Province), and Noling Watershed (Luwu District, South Sulawesi Province). The significant positive and very significant positive are generally the same, only differentiated by the level of significance and both are included in the key location. The location, correlation value (R), and significance value (P) can be seen in detail in Table 1.

For La-Niña conditions, based on the results of the determination of the key area, the total key area in the Niño 3.4 index of all lags has 5 key locations (Figure 3). The distribution of these key areas is set in 4 key area classifications "very strong negative correlation which is assigned as significant", "very strong negative correlation which is assigned as very significant", "strongly negative correlation which is assigned as very significant", and "strongly positive correlation which is assigned as very significant". The correlation classification is assigned as very strongly negative which is significant in 1 location like Taman Roya (Jenepondo district, South Sulawesi Province). The strongly positive correlation which is
assigned as significant is at 1 location like Taman Roya (Jeneponto district, South Sulawesi Province). The correlation classification is assigned as very strongly negative which is assigned as very significant in 1 location like Taman Roya (Jeneponto district, South Sulawesi Province). In the conditions in the field, the strongly negative correlation-significant and strongly negative correlation-very significant both are the same as the key location. Significance refers more to the level of confidence.

The strongly positive correlation- assigned as very significant has locations, namely Muui (Hulu Sungai Tengah District, South Kalimantan Province) and Haruai Muui (Tabalong District, South Kalimantan Province). In this classification, there are key locations that represent several lags Muui (lag 1 and lag 3) and Haruai Muui (lag 1, lag 2, and lag 4). The location, correlation value (R), and significance value (P) can be seen in detail in Table 2.

Figure 2. Map of key locations as indicators for extreme climate impact based on Niño 3.4 in El-Niño conditions

Table 1. Key locations as indicators for extreme climate impact based on Niño 3.4 in El-Niño conditions.

| Province            | District/City | Rainfall Station | Lag | Correlation (>0.5 or <0.5) | Significance (α <0.1) | Classification                      |
|---------------------|---------------|------------------|-----|-----------------------------|-----------------------|-------------------------------------|
| DI Yogyakarta       | Gunung Kidul  | Nglipar          | 4   | 0.506                       | 0                     | Strongly Positive Correlation – Very Significant |
| East Kalimantan     | Paser         | Tanah Grogot     | 2   | -0.511                      | 0                     | Strongly Negative Correlation - Very Significant |
| Central Kalimantan  | Barito Utara  | Muara Teweh Tengah | 4   | 0.552                       | 0.009                 | Strongly Positive Correlation – Very Significant |
Based on the results of the analysis, it has been found that the key locations and their distribution throughout Indonesia in El-Niño and La-Niña conditions. Rainfall in this key location has a strong/very strong and very significant/significant correlation to SST Niño 3.4. This means that the phenomenon of extreme climate events that can be monitored through the SST Niño 3.4 index greatly affects the pattern, intensity, and distribution of rainfall. Monitoring needs to be done to know the possibility of an extreme climate that will occur so that anticipation can be done. The closeness of the relationship between rainfall and the global index also resulted from the research of [23,24].

Figure 3. Map of Key locations as indicators for extreme climate impact based on Niño 3.4 in La-Niña conditions.
Table 2. Key locations as indicators for extreme climate impact based on Niño 3.4 in La-Niña conditions.

| Province         | District/City | Rainfall Station | Lag | Correlation (>0.5 or < -0.5) | Significance (α < 0.1) | Classification                  |
|------------------|---------------|------------------|-----|------------------------------|------------------------|---------------------------------|
| Banten           | Tangerang     | Cikasungka       | 3   | 0.534                        | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Hulu Sungai Tengah | Muui            | 1   | -0.534                       | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Hulu Sungai Tengah | Muui            | 3   | -0.534                       | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Tabalong      | Haruai Muui      | 1   | -0.511                       | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Tabalong      | Haruai Muui      | 2   | -0.532                       | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Tabalong      | Haruai Muui      | 4   | -0.535                       | 0                      | Strongly Positive Correlation – Very Significant |
| Lampung          | Lampung Selatan | Metro DPU       | 2   | 0.515                        | 0                      | Strongly Positive Correlation – Very Significant |
| South Kalimantan | Jeneponto     | Tamanroya        | 1   | -1                           | 0.055                  | Strongly Negative Correlation - Significant |
| South Kalimantan | Jeneponto     | Tamanroya        | 2   | -1                           | 0.100                  | Strongly Negative Correlation - Significant |
| South Kalimantan | Jeneponto     | Tamanroya        | 3   | -1                           | 0.060                  | Strongly Negative Correlation – Very Significant |

For the agricultural sector, rainfall greatly determines the time and type of agricultural activities (planting area and time, harvested area and production) because it is related to water availability. The key locations generated in this analysis are mostly in food production centres, especially rice. In the agricultural sector, extreme climate El-Niño and La-Niña generally result in flooding and drought. This means that extreme climate events will greatly impact the decline in planting area and production due to agricultural land affected by flooding and drought and even attacks by Plant Pest Organisms. This is also revealed from the research results [25,26,27,28,29,30,31] which states that extreme climate events and rainfall variability greatly affect agricultural production.

In order to support adaptation strategy on climate change, adaptation efforts can be carried out by understanding the magnitude of the impact and monitoring such impact on the identified key locations. Rainfall in key locations can be used as a basis for modeling the relationship with the planted area, harvested area, and production so that the magnitude of the impact of climate events on both El-Niño and La-Niña conditions can be determined and monitored. Key locations are priority locations in adaptation programming and action. For example, based on the forecast results from the Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG) it is predicted that La-Niña will occur within the next one season (rainy season) which will have an impact in the form of increased rainfall, a climate information utilization program can be developed water management for increased agricultural production. Actions that can be taken include monitoring the development and prediction...
of rain in coordination with the BMKG, preparing seeds and varieties that are resistant to inundation (Inpara 5, Inpara 6, Inpari soaking, Inpari 30, Ciherang sub-1, and others), preparation of fertilizers and agricultural machinery, disposal excess water in paddy fields and repair drainage channels. Synchronization of programs and actions will facilitate their implementation in the field, supported by cooperation and coordination between stakeholders so that all impacts of extreme climate can be minimized.

4. Conclusions
Based on the results of this study, there is a strong and significant correlation between rainfall and SST Niño index 3.4. This information is important considering SST Nino 3.4 is a very influential indicator of rainfall in Indonesia. Rainfall in key locations that have been identified has a strong and significant correlation to SST Nino 3.4 and is a priority location. Analysis of the impact of extreme climates (El-Niño and La-Niña) and monitoring them in key locations can be used as a reference in preparing action programs to anticipate extreme climates so that risks can be minimized. Updating data and compiling information systems are needed so that any developments in climate variability and anomalies can be monitored and can be accessed more quickly.

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