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ASSESSING THE IMPACT OF CLIMATE CHANGE ON LANDSLIDE FREQUENCY IN NAKHON SI THAMMARAT PROVINCE, THAILAND

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ABSTRACT: Landslides are a form of hydro-geohazard causing significant damage to property, infrastructure, and even loss of life. The occurrence of landslides is significantly influenced by changes in daily rainfall due to climate change and climate variability. Hence, this study aims to predict changes in landslide frequency under the influence of climate change. Utilizing five CMIP6 climate models under SSP2-4.5 conditions to predict future rainfall, global climate model simulations of rainfall are adjusted and corrected using the linear scaling bias correction technique. To determine the critical rainfall threshold, the rainfall threshold for landslide early warning was utilized, implemented with rain gauges. The analysis performed was used to predict changes in landslide frequency over the next 20 years, divided into four periods between 2023 and 2042. To analyze the changing landslide frequency, the future period was compared against the historical period from 2010 to 2014. The results obtained show a fluctuating landslide frequency in Nakhon Si Thammarat province, Thailand. Nevertheless, the analysis indicates a general trend of increasing landslide frequency compared to the historical period. In the eastern part of the province, the number of excess rainfall days is found to be higher than in the western part of the province.

Keywords: Landslide, Climate Change, Antecedent Precipitation Model, Climate Model, Heavy Rainfall

1. INTRODUCTION

Landslides are hydro-geohazards that cause damage to infrastructure and housing and pose significant threats to human safety. Considering historical landslide events, heavy rainfall plays a key role in landslide occurrence in Thailand. For example, on 11 August 2001, landslides and debris flows in the Nam Ko Yai village in Lom Sak district, Phetchabun province, Thailand, caused more than 5 million dollars of property damage [1]. The cause of these landslides and debris flows was heavy rainfall over Khao Ko Mountain and Phu Hin Rong Kla Mountain. The nearest rain gauge recorded more than 150 mm of rainfall during the period 1-10 August 2001 [2]. Thailand experiences frequent landslides, especially in the northern, western, and southern parts of the country, and the frequency of extreme or heavy rainfall occurrences is projected to increase due to climate change [3,4,5]. Therefore, it is of critical importance to study the change in the frequency of landslide occurrence in Thailand. Historical landslide records indicate that heavy rainfall is the most significant factor in triggering large-scale landslides in Thailand [6].

The general circulation model is an extensively utilized method for projecting long-term climate patterns [7]. The simulated precipitation from GCM provides significant input data for landslide simulation [8,9]. For example, Chen [10] used the MRT-AGCM, as a GCM in CMIP5, to simulate the frequency of landslide occurrence in the Xindian River catchment area of Northern Taiwan under RCP8.5 conditions. CMIP6 is a current Scenario Model Intercomparison Project (ScenarioMIP) which utilizes the shared socio-economic pathways (SSP) scenario to simulate future development pathways related to greenhouse gas emissions [11].

In recent years, numerous studies have proposed methods that integrate landslide models with simulated precipitation data derived from Global Climate Models (GCMs) [12]. Various approaches have been developed to couple projected precipitation from GCMs with landslide modelling. Several studies have employed statistical models such as logistic regression and weighting techniques, in which simulated precipitation is used as an input variable [13]. Additionally, some research has used projected precipitation as flux input to estimate volumetric water content or groundwater levels [14]. These approaches often involve coupling hydrological models with geotechnical models using either deterministic or probabilistic frameworks [15,16]. Moreover, machine learning and deep learning techniques are increasingly applied to map landslide susceptibility areas under changing climatic conditions [17]. However, the aforementioned methods typically require extensive input data and high-performance computing resources to effectively simulate the impacts of climate change on landslide occurrence. Considering the challenges associated with landslide early warning systems, the use of critical rainfall thresholds has proven to be an effective and practical approach currently in use [18]. These thresholds are empirical relationships derived from rainfall characteristics such as total rainfall, antecedent rainfall, or rainfall duration, observed during past landslide events. Various types of rainfall thresholds have been developed for shallow landslides, including intensity–duration thresholds and the antecedent precipitation index [19].

This study aims to assess the impact of future precipitation changes, driven by climate change and climate variability, on landslide frequency by employing five Global Climate Models (GCMs) from the CMIP6 ensemble under the Shared Socioeconomic Pathway (SSP) scenario SSP2-4.5. This scenario assumes that development patterns and energy consumption remain consistent with historical trends. The critical rainfall threshold for southern Thailand is applied to classify and interpret the future precipitation projections derived from the selected CMIP6 GCMs.

2. RESEARCH SIGNIFICANCE

Climate change and climate variability are critical factors contributing to the occurrence of hydro-geohazards such as landslides and debris flows. In recent years, Thailand has experienced an increase in extreme rainfall events, primarily driven by these climatic shifts. The increase in heavy rainfall has led to more frequent and severe landslides across the country. Therefore, it is essential to assess the projected impacts of future precipitation changes induced by climate change. Additionally, a key challenge lies in developing robust methodologies to effectively integrate climate model outputs with landslide early warning systems.

3. STUDY AREA

Nakhon Si Thammarat is situated on the east coast of southern Thailand. Geographically, the province can be categorized into three distinct regions: the eastern coastal plains, the western plains, and the mountainous area. The Nakhon Si Thammarat Mountain range is in the central part of the province and stretches from north to south within the province. Geologically, the mountainous region of Nakhon Si Thammarat province is mainly composed of granite. Granitic rock has a high sensitivity to landslides in Thailand [20]. In other areas of the province, the geological composition includes sandstone, siltstone, limestone, as well as alluvial and colluvial deposits. Climatically, Nakhon Si Thammarat province is influenced by the northeast and southwest monsoons, with an average annual precipitation of approximately 2700 mm. November is the wettest month. Nakhon Si Thammarat province has experienced disastrous landslide and debris flow occurrences throughout recent history, such as landslides in 1988 and 2011 [20]. Fig.1 presents the study area and elevation.

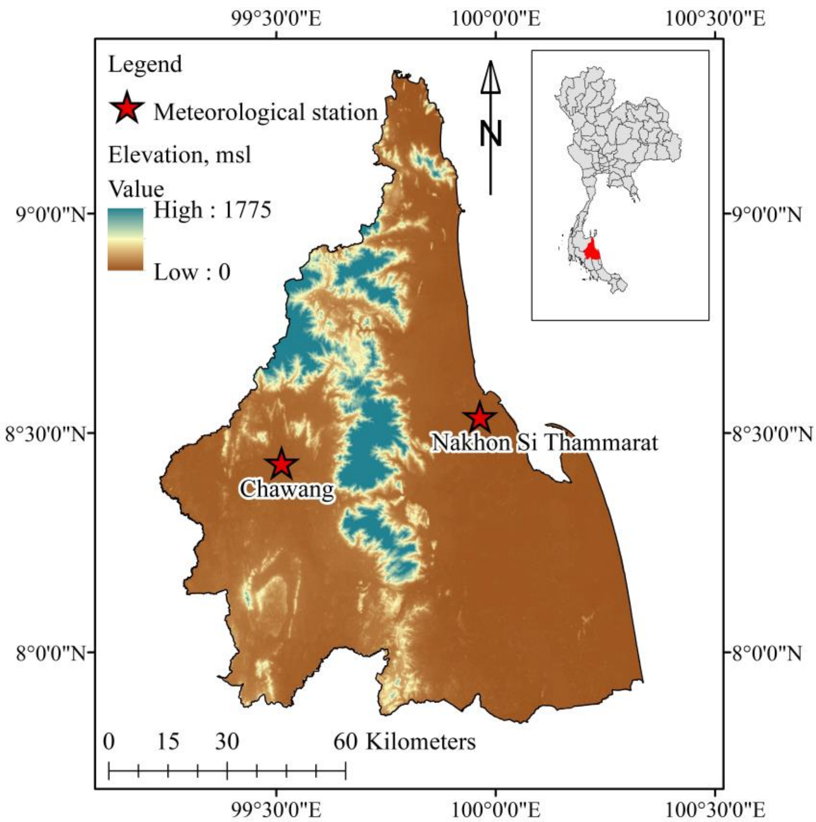

Fig.1 Study area and elevation

4. METHODS AND DATA

4.1 Methods

The analytical procedure performed in this study is divided into two parts. Firstly, the simulated precipitation from GCMs undergoes downscaling and bias adjustment using the linear scaling method. The linear scaling method can be expressed by Eq. (1) as follows.

$$P_{bias,i,j} = P_{GCM,i,j} \times \left[\overline{P_{obs,i}} / \overline{P_{GCM,i}} \right] \quad (1)$$

where $P_{bias,i,j}$ is the adjusted precipitation for the j^{th} day of the i^{th} month; $P_{GCM,i,j}$ is the precipitation of GCMs for the j^{th} day of the i^{th} month; $\overline{P_{obs,i}}$ is the mean value of observed precipitation in a given month; and $\overline{P_{GCM,i}}$ is the mean value of precipitation from the GCMs in a given month. A seventeen-year period (1998 to 2014) of measured rainfall data and simulated precipitation from GCMs provides a historical period for downscaling and the bias correction process. The root mean square error (RMSE) is utilized to assess the performance of downscaling and the bias correction process. Secondly, the critical rainfall threshold is used to detect the number of excess rainfall days. The results of each GCM are then coupled using the ensemble mean method. The critical rainfall threshold is developed based on the relationship of daily rainfall and three-day accumulated rainfall [21]. The future period of landslide frequency analysis (2023 to 2042) is divided into four periods: future period 1 (2023–2027), future period 2 (2028–2032), future period 3 (2033–2037), and future period 4 (2038–2042). Fig. 2 presents the critical rainfall threshold for Southern Thailand

4.2 Data

Observed rainfall data from 1998 to 2020 were collected at the Nakhon Si Thammarat and Chawang meteorological stations (see locations in Fig. 1). The Nakhon Si Thammarat meteorological station is located at the eastern part of the province in which the northeast monsoon has a relatively high influence. The Chawang meteorological station is located in the western part of the province under the influence of the southwest monsoon. The Nakhon Si Thammarat Mountain range acts as a barrier to monsoons within the study area [22].

For simulated precipitation using GCMs, this study utilizes five GCMs of CMIP6 under SSP2-4.5 conditions to assess the effect of changing climate on landslide frequency in Nakhon Si Thammarat province. Table 1 summarizes the details of the GCMs used.

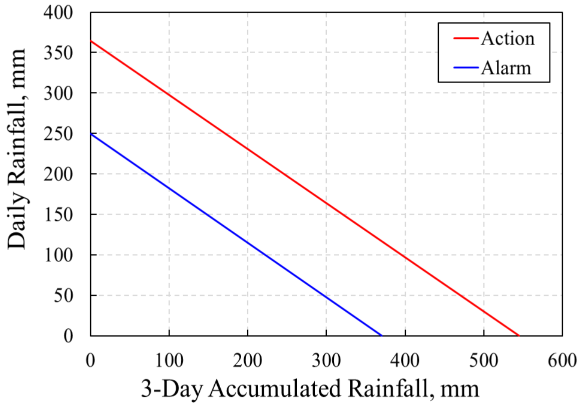

Fig.2 Critical rainfall threshold for Southern Thailand

5. RESULTS AND DISCUSSION

Following the bias correction and downscaling processes, the simulated precipitation from GCMs was adjusted according to the linear scaling method. The average RMSE of adjusted precipitation from GCMs decreased by approximately 19% for Chawang meteorological station and by approximately 16% for Nakhon Si Thammarat meteorological station when compared with the raw precipitation from GCMs prior to bias correction and downscaling. The RMSE showed that the bias correction and downscaling process removed the error from the simulated GCM precipitation. Fig. 3 shows the RMSE values before and after downscaling and bias correlation of data from Nakhon Si Thammarat meteorological station and Fig 4 presents similar data for Chawang meteorological station.

For landslide frequency analysis, the critical rainfall threshold for the landslide early warning system was coupled with the corrected precipitation obtained from GCMs. Three zones of critical rainfall threshold were identified: the safe zone, the alarm zone and the action zone. When the precipitation rises to the alarm zone, local people must prepare for evacuation. Under action zone conditions, the local people must evacuate to the evacuation center. According to analyses from Nakhon Si Thammarat meteorological station, the average number of excess rainfall day in the alarm zone will increase during future period 1 (2023–2027), continue to increase during future period 2 (2028–2032) and future period 3 (2033–2037), then decrease during the future period 4 (2038–2042) according to comparisons with the historical period (2010–2014). For the action zone, Nakhon Si Thammarat meteorological station data indicate that the number of excess rainfall days will reduced during future period 1 (2023–2027) and increase during future period 2 (2028–2032) and future period 4 (2038–2042). No change in excess rainfall days is predicted in future period 3 (2033–2037). Fig 5 shows the percentage of change in the number of excess rainfall days and Fig 6 presents the critical rainfall threshold and corrected precipitation, both based on IIT-ESM for Nakhon Si Thammarat meteorological station.

Table 1 The details of GCMs for the study [9]

Model name	Resolution (Longitude x Latitude)	Modeling center
INM-CM4-8	2º×1.5º	Institute of Numerical Mathematics (INM), Russia
IIT-ESM	1.875º×1.9º	Indian Institute of Tropical Meteorology, India
MPI-ESM1-2-LR	1.5º×1.5º	Max Planck Institute for Meteorology, Germany
CNRM-ESM2-1	1.0º×1.0º	Centre National de Recherches Meteorologiques, France, Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique (CNRM-CERFACS), France
CNRM-CM6-1	1.0º×1.0º	Centre National de Recherches Meteorologiques, France, Centre Europeen de Recherche et de Formation Avancee en Calcul Scientifique (CNRM-CERFACS), France

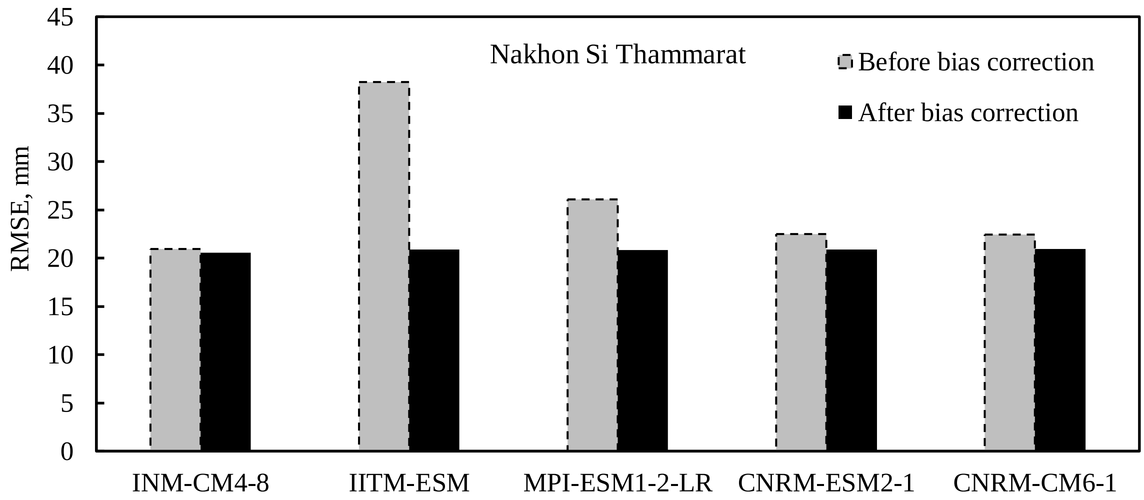

Fig.3 RMSE values for before and after downscaling and bias correlation of Nakhon Si Thammarat meteorological station.

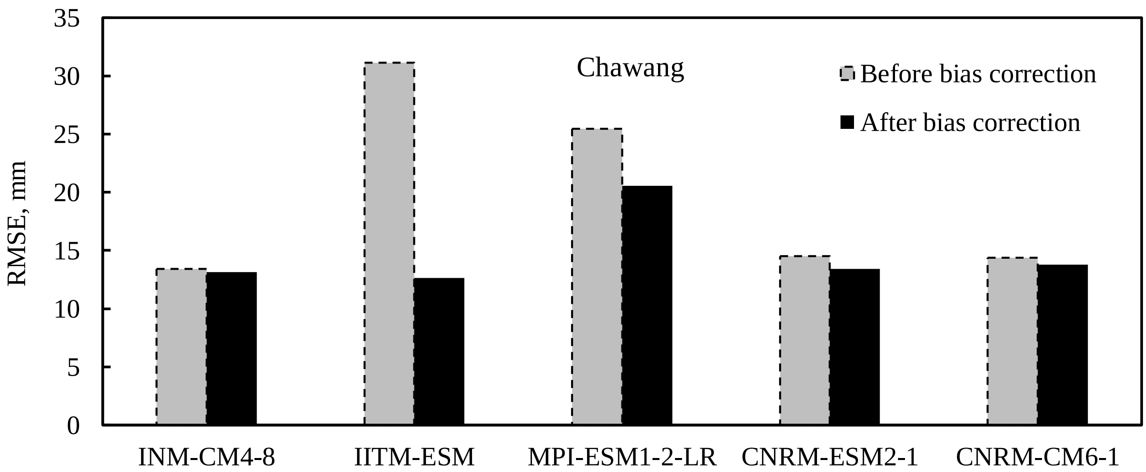

Fig.4 RMSE values for before and after downscaling and bias correlation of Chawang meteorological station.

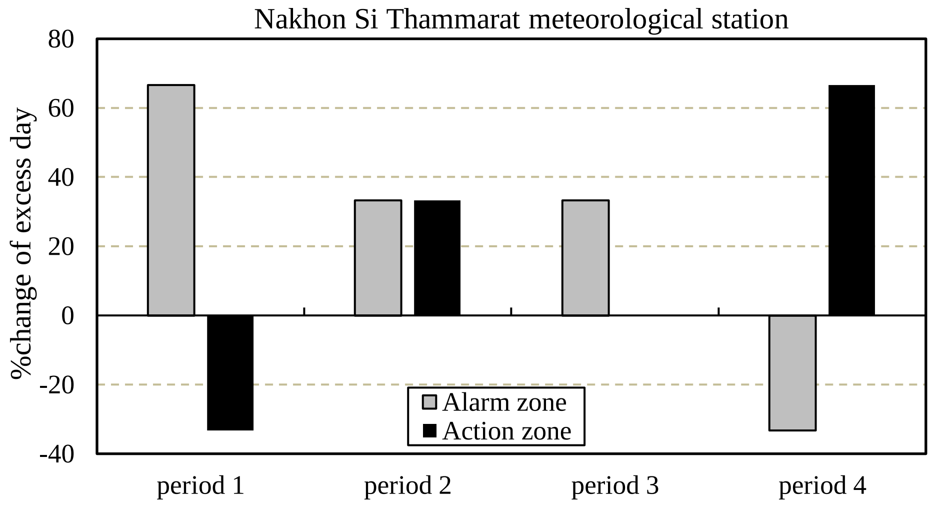

Fig.5 Percentage of change of number of excess rainfall day for Nakhon Si Thammarat meteorological station.

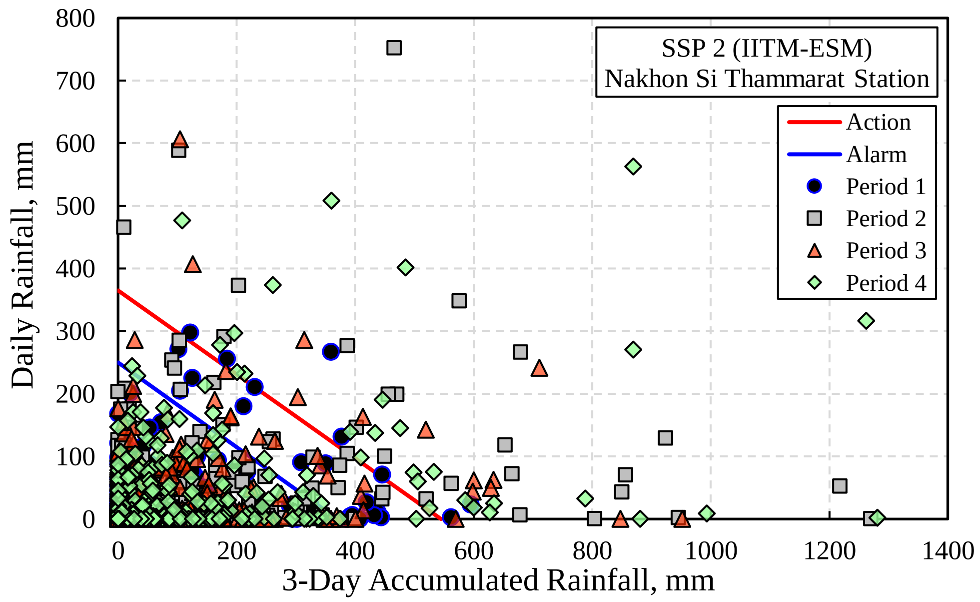

Fig.6 Plot of critical rainfall threshold and corrected precipitation from IIT-ESM for Nakhon Si Thammarat meteorological station

For Chawang meteorological station, the number of excess rainfall days at alarm zone is predicted to continuously decrease from future period 1 (2023–2027) until future period 4 (2038–2042) based on comparison with the historical period (2010–2014). For the action zone, the trend in the number of excess rainfall day predicted to fluctuate. The number of excess rainfall days is predicted to significantly decrease during future period 1 (2023–2027), increase in future period 2 (2028–2032), slightly decrease in future period 3 (2033–2037) and increase in future period 4 (2038 to 2042). Fig 7 presents the percentage of change of number of excess rainfall days for Chawang meteorological station and Fig 8 presents the plot of critical rainfall threshold and corrected precipitation from IIT-ESM.

In terms of the number of excess rainfall days between the Nakhon Si Thammarat and Chawang meteorological stations, it was found that the number at Nakhon Si Thammarat meteorological station in the eastern part of the province, is higher than that at Chawang meteorological station in the western part of the province. This can be explained by the barrier to monsoons formed by the Nakhon Si Thammarat Mountain range. The northeast monsoon brings a large amount of rainfall to the eastern part of Nakhon Si Thammarat [23,24]. The western part of province is in the rain shadow, leading to less rainwater than in the eastern part of province. However, the western part of the province is influenced by the southwest monsoon.

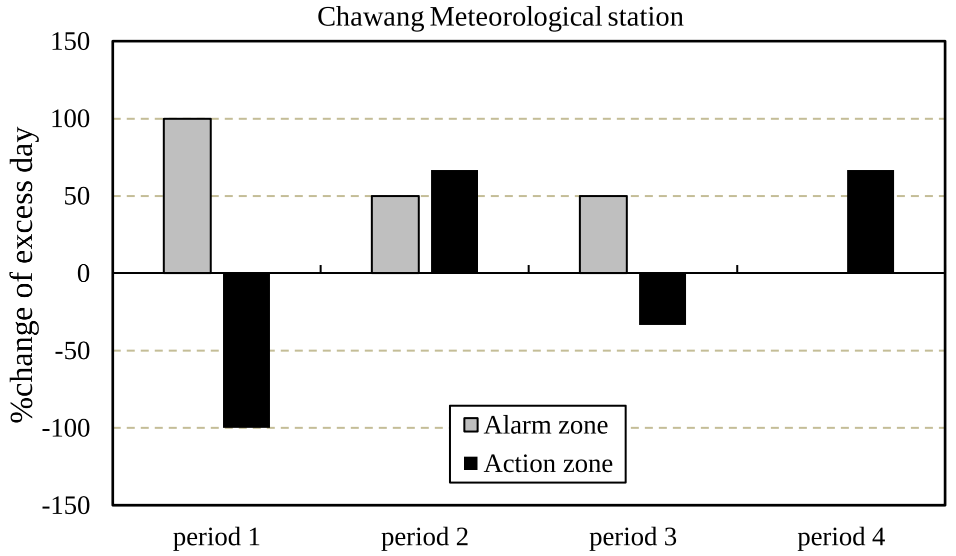

Fig.7 Percentage of change of number of excess rainfall day for Chawang meteorological station

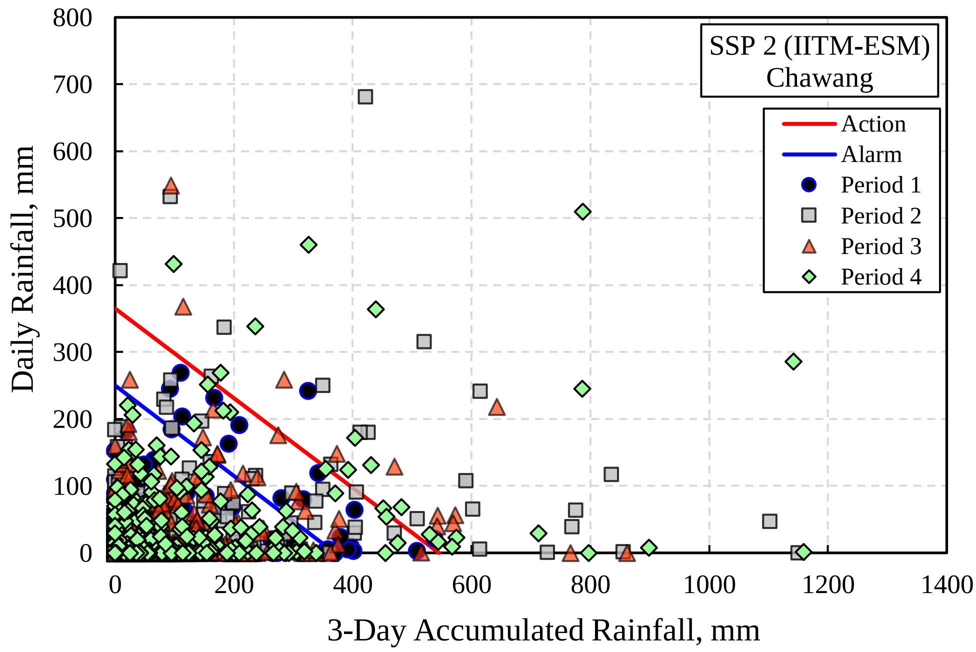

Fig.8 Plot of critical rainfall threshold and corrected precipitation from IIT-ESM for Chawang meteorological station.

6. CONCLUSIONS

In this study, the number of excess days of rainfall in Nakhon Si Thammarat province, Thailand, was determined by coupling the critical rainfall threshold and predicted future precipitation based on the CMIP6 Multi-Model Ensemble under SSP2-4.5 conditions. The period of analysis was separated into five periods: the historical period (2010–2014), future period 1 (2023–2027), future period 2 (2028–2032), future period 3 (2033–2037), and future period 4 (2038–2042). According to the analyses performed, the overall trend of changes in landslide frequency is predicted to show an increase, albeit with significant fluctuation depending on the future period considered. The average number of excess rainfall day in the alarm zone is expected to increase significantly in the future, posing a substantial challenge for the landslide early warning system and evacuation preparedness efforts. The eastern part of Nakhon Si Thammarat province is more susceptible to landslide occurrences due to the influence of topography and monsoons.

7. ACKNOWLEDGMENTS

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