Water Crisis Management in Rainfed Agriculture – The Context of Flash Flood and Drought in Thailand

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Abstract

In the context of water crisis management, the urgent need for water resources management in agriculture and disaster management to meet future food and livelihood needs is highlighted, especially given the pressure and stress on water management and the uncertainty caused by climate variability. Rainfed agriculture in Thailand's rural areas plays and will remain an important role in providing food, generating livelihoods, and ensuring water security. The primary aims of the project are to forecast and evaluate the flash flood guidance system and the seasonal drought forecasting system. The case study for real-time hydrological forecasting of flash flood risk is during the tropical storm "SINLAKU" on August 2–5, 2020. For the seasonal drought forecasting system, the water balance process has been used to determine water deficit areas at the sub-district level in the dry season from 2019 to 2020. Furthermore, disaster management is being used to establish the water crisis prevention and mitigation plan prior to, during, and after a disaster. As a result, water crisis prevention and mitigation procedures have been implemented in rainfed agriculture to reduce the severity of disasters.

Keywords: Rainfed agriculture, Flash flood guidance system, Drought forecasting system, Water crisis management

1. Introduction

The agricultural sector plays an important role in economic development [1] and poverty alleviation [2]. However, a significant number of poverty households in Asia still face hunger, food security, and malnutrition where rainfed agriculture is the main agriculture activity [3]. The significance of rainfed agriculture is varied on regional and climate conditions but mainly contributes to food for poor communities in developing countries. Nevertheless, the challenges of rainfed agriculture are complicated by climate variability, climate change, population growth, health pandemics, degrading natural resources base, poor infrastructure, and land-use change [2],[4].

Experts predict further declines in precipitation and magnifications of extreme events [5]. Therefore, the world likely is facing a water crisis with little room for further expansion of large-scale irrigation [6]. This emphasizes the need for water resources management in rainfed agriculture, securing the water for the production sector, and building resilience for the agriculture sector. Hence, rainfed agriculture will play a key role in providing food and livelihood to alleviate poverty in rural areas.

In Thailand, the water resources are managed by an area-based approach consisting of irrigation and rainfed agriculture. The agricultural areas are approximately 238,720 km^2. The irrigation area is about 52,400 km^2 (22% of the agriculture area), whereas the other 78% is the rainfed agriculture covers around 187,200 km^2 [7]. In the master plan on water resources management contexts, the master plan is a framework and guideline for solving water resources problems in terms of natural resources and economic and social issues to increase national water security.

For the above reasons, the main objective of this paper is to express the water crisis management in rainfed agriculture in Thailand, including the flash flood warning system, the seasonal drought forecasting system, and the water crisis prevention and mitigation, respectively.

2. Flash Flood Warning System

A flash flood is a short and sudden local flood with significant volume. It has a limited duration which follows within a few hours of heavy or excessive rainfall [8]. Due to its characteristics, it is difficult to address the flash flood using the traditional flood forecasting system used for the lowland riverine flood. Compared with the riverine flood, flash flood often occurs in mountainous areas or the foothills due to the steep slope and thin surface soil layers in rainfed agriculture [9]. In terms of warning, a flash flood is a local hydrometeorological phenomenon that requires hydrological and meteorological tools for real-time forecasting and warning (24/7 operation). Moreover, flash flood forecasting and warning systems require more specific measures based on the characteristics of the flash flood. The Department of Water Resources (DWR) has used this system to forecast flash flood events in mountainous areas. Therefore, this section expresses the results of DWR's flash flood guidance system and early warning system.

2.1. Flash Flood Guidance System

The Flash Flood Guidance System (FFGS) was implemented to evaluate the flash flood risk for Haiti before the heavy precipitation, landslides, and debris flow of Hurricane Tomas in November 2010 [10] and employed to predict the flash flood risk during the typhoon season in Southern Thailand between November to December 2017 [11]. The evaluation results of FFGS were verified in terms of Mean Areal Precipitation (MAP), Forecasting Mean Areal Precipitation (FMAP), Average Soil Moisture Content (ASM), and Flash Flood Risk (FFR) in Haiti and Thailand. The FFGS products satisfactorily reproduced MAP, FMAP, ASM, and FFR for the evaluation results. Recently, Flash Flood Potential Index (FFPI) and Dynamic Flash Flood Hazard Index (DFFHI) were developed in Thailand for forecasting the flash flood by considering physical-geographic factors, rainfall index, and soil moisture index [12–13]. Both recent studies found that FFPI and DFFHI can be used for flash flood forecasting. However, the forecasters who need to adjust the flash flood forecasting system must consider the in-situ stations for implementing the system.

For the FFGS, further information is given by E. Shamir et al. [10] and S. Patsinghasanee et al. [11]. This section evaluated the FFGS for the real-time hydrological forecasting of flash flood risk during the tropical storm "SINLAKU" from August 2–5, 2020. Heavy rainfall over Northern Thailand has influenced the weather conditions since August 2, 2020. After that, the tropical storm moved into the South China Sea and weakened to a tropical depression over Lao PDR and Northern Thailand on August 3, 2020. In addition, a tropical depression was quickly dissipated to the low-pressure cell in Northern Thailand. For the following reasons, heavy rainfall was developed over Northern

Thailand. The daily rainfall reported by the Thai Meteorological Department (TMD) from August 2–5, 2020, is illustrated in **Fig.1**. Therefore, the preliminary assessment indicated localized flooding in Northern Thailand. However, the disaster report did not provide specific information on the actual type of flooding (e.g., riverine flood, and flash flood) or cause (e.g., flood wave, and debris). The evaluation results of FFGS during "SINLAKU" in Northern Thailand (Chiang Rai, Chiang Mai, Nan, Phrae, and Uttaradit provinces) are verified in terms of MAP, FMAP, and FFR, respectively. The evaluation results are as follows.

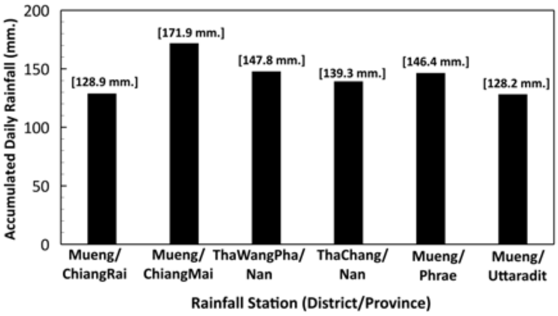

Figure 1 Accumulated Daily rainfall during August 2–5, 2020

The MAP products and observed data (TMD) were compared with the perfect agreement line, which fell within a 30% error line (**Fig.2**), and the correlation value (R^2) is 0.73. Nevertheless, many points fell outside the 30% error line capturing that the estimated daily MAP by FFGS was significantly underestimated compared to the observed daily rainfall. Furthermore, the FMAP products and observed data (TMD) were compared with the perfect agreement line, which fell outside a 30% error line (**Fig.3**), and the correlation value (R^2) is 0.46. Therefore, it was concluded that the FMAP dramatically underestimated observed daily rainfall. For this reason, the local forecasting rainfall systems, radar stations, and forecaster abilities are essential to consider with the FMAP product for making a good decision for disaster management agency.

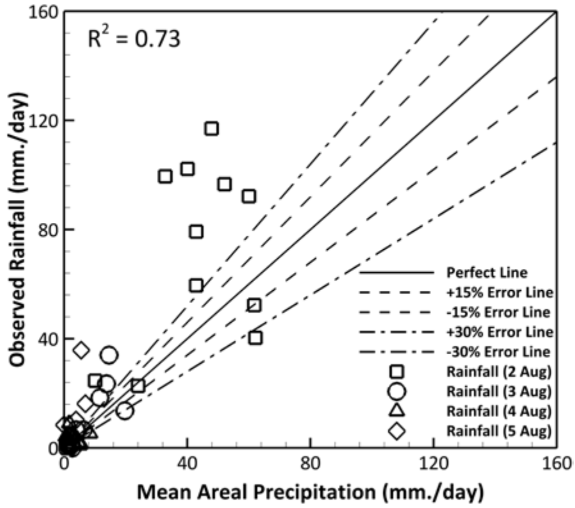

Figure 2 Comparison results between MAP and observed data during August 2–5, 2020

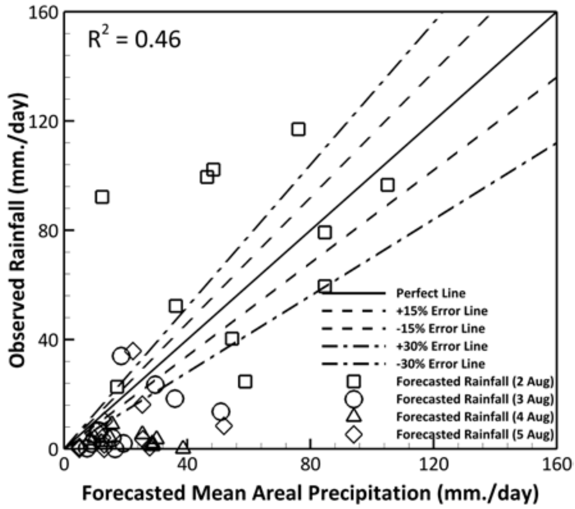

Figure 3 Comparison results between FMAP and observed data during August 2–5, 2020

The FFGS produced a product to identify the flash flood risk area during the passing of a low-pressure cell. The FFR product was compared with the inundation areas reported by the disaster management agency [14]. However, the inundation areas did not specify the actual type of flooding (e.g., flash flood, riverine flood, and debris flow). The comparison results of FFR are exhibited in **Fig.4**. The yellow, orange, and red areas are the flash flood risk generated by FFGS, and the hatched areas are the inundation areas reported by the disaster management agency. The comparison results between FFR products and inundation areas are illustrated in good agreement in Northern Thailand on August 2, 2020.

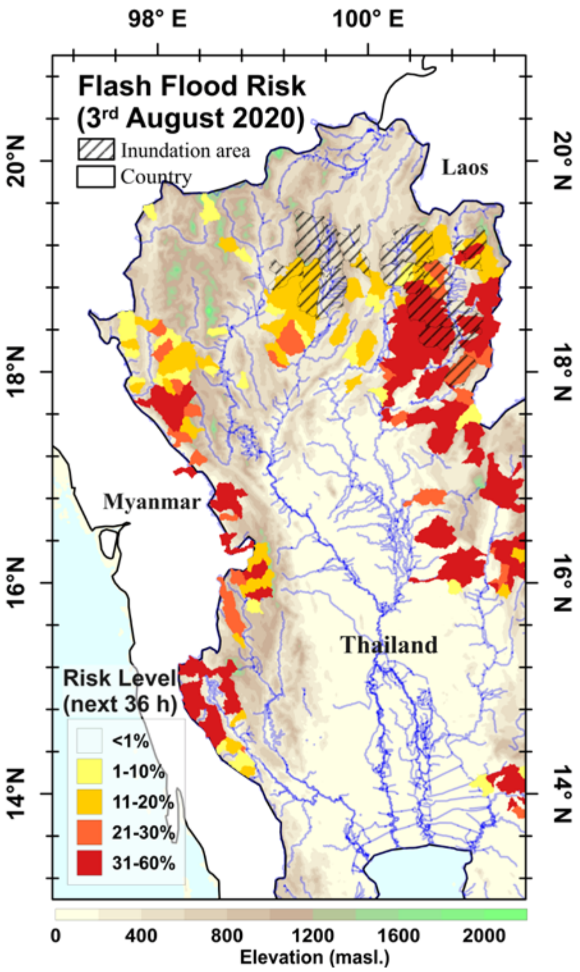

Figure 4 Comparison results between FFR and the inundation areas on August 2, 2020

2.2.Early Warning System

The Early Warning System (EWS) has been installed and operated by DWR to monitor and warn of flash floods in mountainous areas. Approximately 188 times throughout the consideration period, the EWS delivered warning information to policymakers in disaster management agencies and local authorities, covering 606 villages. Furthermore, the evacuation warning (red alert) was issued 8 times in Nan, Chiang Mai, Chiang Rai, Uttaradit, Phitsanulok, and Mae Hong Son (**Fig.5**).

In addition, during the tropical storm "SINLAKU," the DWR's flash flood warning systems used a combination of the forecasting system (FFGS) and in-situ stations (EWS) to clarify the flash flood risk areas in Northern Thailand. The results indicated that the coupling system for the flash flood warning system from DWR effectively implements the actual situation in Northern Thailand.

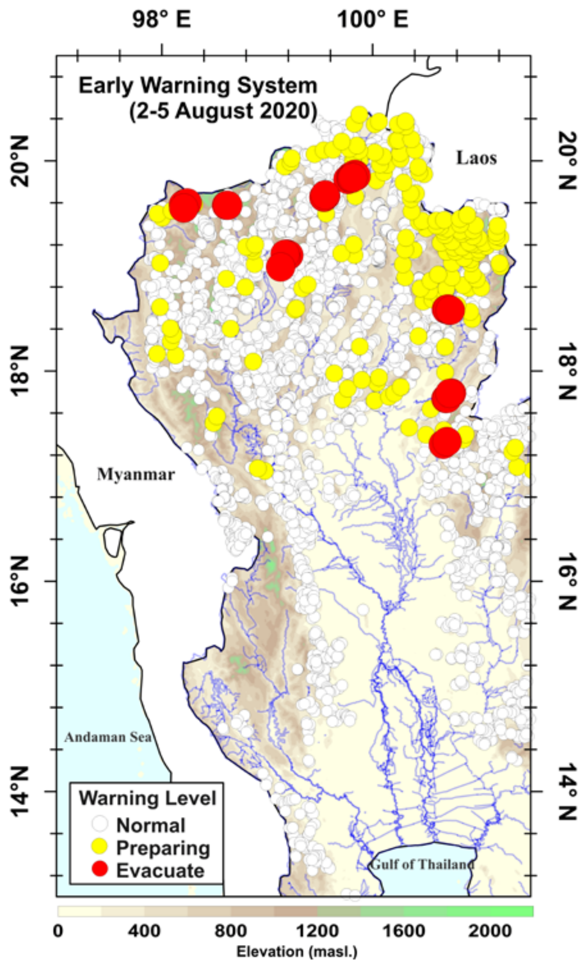

Figure 5 Alarms of the EWS during the tropical storm "SINLAKU" between 2-5 August 2020

3. Drought Forecasting System

Drought, defined by the Master Plan on Water Resources Management (Thailand), is the river discharge or water level steadily decreases, affecting living and growing conditions in the surrounding areas [7]. In addition, the drought definition according to the Disaster Prevention and Mitigation Plan (2010–2014) refers to abnormally less rainfall or a prolonged period of less rainfall, causing deficiencies of drinking water and water scarcity. This condition resulted in water shortages, crop damage, steam flow reduction, and, therefore, low quality of life in the affected area [15]. Moreover, droughts can continue for months or years, and there are consisted of three stages of drought that increase the impact on people in drought-affected areas [16]. The first drought stage is associated with meteorological drought, occurring when the precipitation is consistently less than the average. This stage can also result in other stages. The second stage is an agricultural drought which is a drought that affects agricultural or ecological productivity. Additionally, the last stage is hydrological drought. As a result, the amount of available water in surface and sub-surface water bodies, such as rivers, lakes, reservoirs, and groundwater aquifers, is lowered below the average.

Over the past decades, Thailand has encountered droughts, affecting the economy, agriculture, ecosystem, and industry, due to less annual rainfall than average (1,554 mm). The records have shown that Thailand has 42,880 km^2 of drought risk areas and 7,490 villages with water shortages for consumption (9.98% of villages in the country) [7]. Drought risk analysis and forecasting systems implemented in the past have considered the hydro-meteorological data, irrigation areas, and village water supply systems to predict drought areas at the provincial level [17–18]. After that, the water balance concept was applied in Thailand’s rainfed agriculture by considering the water supply (forecasting rainfall, river discharge, and available water in the water bodies) and water demand (domestic, ecological, agricultural, and industrial uses) in district level [19]. Furthermore, Standardized Precipitation Index (SPI), based on historical data (1985–2016), was used to predict the meteorological drought in the Lower Mekong region [20]. Reconnaissance Drought Index application and daily weather data (temperature, relative humidity, sunlight count, and wind speed) during 1979–2015 were employed to analyze the drought risk areas over Thailand [21]. Furthermore, the Analytic Hierarchy Process (ANP), based on variables including the SPI, the distance from surface water resources, and groundwater yield, was used for agricultural drought assessments in the northeastern region [22]. However, most of these analyses are only based on water supply and hydro-meteorological data, which have not yet considered the water demand as a factor in predicting drought risk areas.

The rainfed agricultures cover 186,320 km^2 or 7,425 sub-districts in Thailand. Rainfall is the primary water supply resource for multipurpose in this rainfed agriculture. However, due to hydro-meteorological uncertainties, such areas are vulnerable to water scarcity [2]. Therefore, to obtain better drought mitigation in rainfed agriculture, this study predicted drought risk at a sub-district level by analyzing the water supply (forecasting rainfall, river discharge, and available water in the water bodies) and the water demand (domestic, agriculture, ecological, and industrial sectors), and evaluating the water balance analysis during the dry season (November 2019–April 2020). The method for analyzing and evaluating the water supply-demand and water balance analysis was detailed by S. Patsinghasanee et al. [23].

4. Water Supply

Water supply evaluation was started at the beginning of the dry season. Therefore, the forecasted rainfall was used to estimate the expected runoff during the period of interest using the Rainfall-Runoff Model (NAM model). The modeling revealed that the forecasting rainfall could change to about 652×10^6 m^3 surface water. It is about 5.3% of the total water supply. Furthermore, another source of water supply in rainfed agriculture was from 102,112 water bodies, with about $8{,}748 \times 10^6$ m^3 (74.3% of total water supply), and the amount of water available from streams flowing through the given areas. The flow rate from the 137 runoff stations showed that 2,366 × 10^6 m^3 of river water (20.1% of total water supply) could be used as a water supply during the dry season. Therefore, the total water supply for the rainfed areas during the dry season was approximately 11,766 × 10^6 m^3, as shown in **Fig.6**.

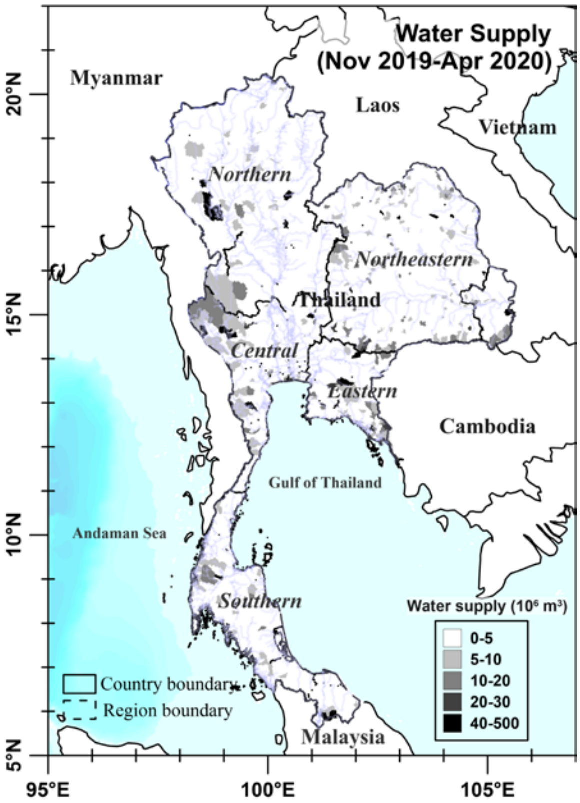

Figure 6 Water supply in the dry season 2019/2020 in the rainfed agriculture

4.1.Water Demand

The water demand estimation includes the four sectors: domestic water use, agricultural demand, ecological conservation, and industrial usage. The result showed that 927 × 10^6 m^3 of water was required for domestic use (11.7% of total water demand). Agriculture water demand by considering the dry-season farming showed a plan for planting 3,520 km^2 of paddy field, 1,360 km^2 of maize, 4,576 km^2 of sugarcane, and 2,544 km^2 of cassava which were estimated at 5,692 × 10^6 m^3 of water demand (71.5% of total water demand). The water used to preserve the ecosystem and industrial sectors was approximately 937 × 10^6 m^3 (11.8% of total water demand) and 401 × 10^6 m^3 (5.0% of total water demand), respectively. As a result, the total water demand for rainfed agriculture during the dry season was about 7,957 × 10^6 m^3. The intense water demand was seen in the lower northern and upper central regions due to multiple cultivations a year (**Fig.7**).

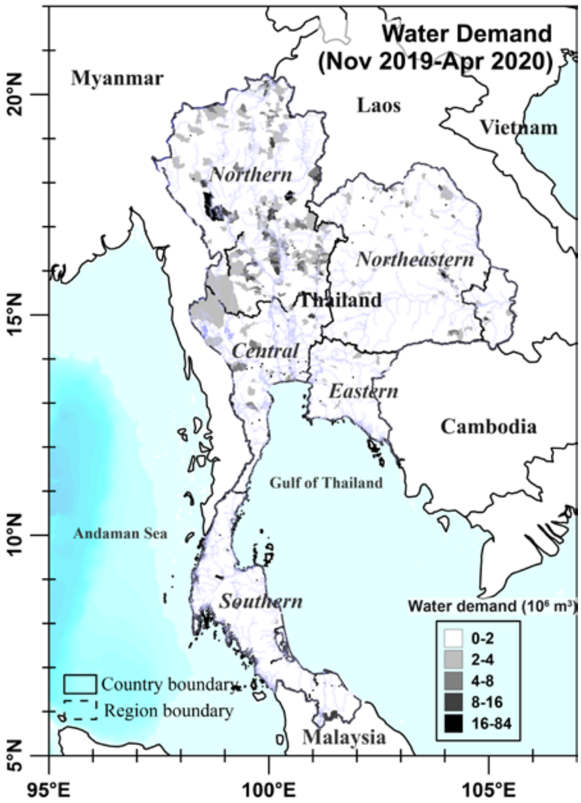

Figure 7 Water demand in the dry season 2019/2020 in the rainfed agriculture

4.2.Water Balance

Water balance in rainfed agriculture during the dry season was analyzed based on water supply and demand at the sub-district level. The results displayed that drought risk areas covered 984 sub-districts of 305 districts of 57 provinces (**Fig.8**). Severe drought risk areas were found in the lower northern and upper central regions, corresponding to the water demand. On the other hand, mild drought risk areas were seen in Northeastern Thailand. Furthermore, the result was consistent with other observations at 71% of forecasted drought areas. For example, the Department of Disaster Prevention and Mitigation reported that water scarcity occurred in 782 sub-districts of 145 districts of 24 provinces in the meantime.

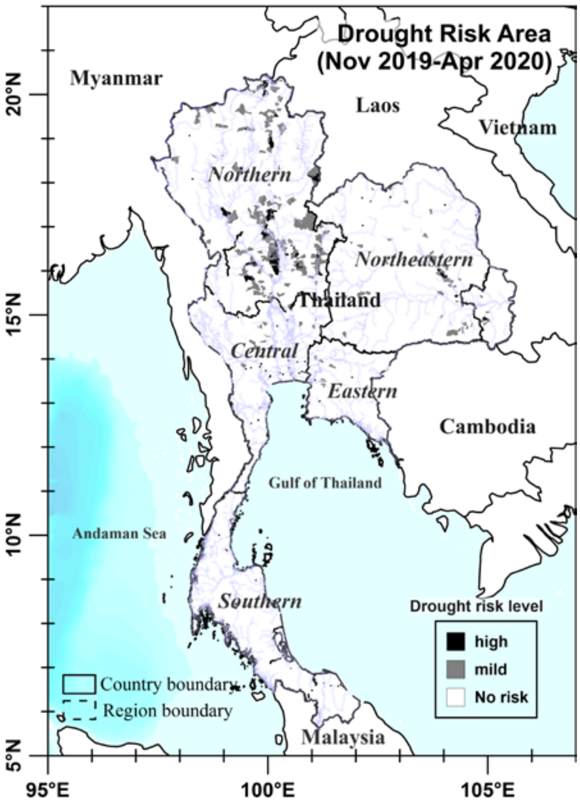

Figure 8 Drought risk areas in the dry season 2019/2020 in the rainfed agriculture

5. Discussion on Water Crisis Prevention and Mitigation

Water crisis prevention and mitigation measures by DWR were adopted to minimize the magnitude of water disasters in rainfed agriculture mainly. The measurements were taken to improve the efficiency of water resource management and reduce the impact of water disasters. Disaster management was employed to prepare the water crisis prevention and mitigation plan before, during, and after the disaster strikes. The disaster management is detailed as the following.

5.1. Prevention and Mitigation Measures

The prevention and mitigation measures are the pre-disaster management for reducing the losses of life and property from water disasters. Moreover, the impacts are felt by human suffering and property damage and loss of livelihood, economic deterioration, and environmental destruction. Therefore, DWR considered the issues and needs associated with implementing a national disaster agency and the provincial offices of natural resources and environment as described in the following information.

Flash flood and drought risk assessments for sub-district levels in rainfed agriculture were generated by applying the techniques of hydrology and water resources management. Information on water resources is critical for monitoring and warning a water crisis in high-risk areas. Each phase of the disaster management cycle must be made that requires getting the right information to the right people at the right time. Therefore, decisions are made in both the public and the private sectors and often at local or individual levels. Moreover, raising awareness of forecasting and warning systems is contingent upon comprehensive promotion. The problem is how to make this information available to many groups strategically. First, DWR planned awareness-raising activities to define the target group. Following that, we assigned each group a topic and selected an appropriate strategy.

6. Preparation Measures

The preparation measures for preventing and mitigating water crises in rainfed agriculture consist of mitigation plans and warning systems. The details of preparation measures in rainfed agriculture are as follows.

A mitigation plan at the local level by DWR was initiated with all those interested: those at risk, those who are competent in assisting risk reduction activities (e.g., crisis service, water management service, and forecasting service). Therefore, cooperation and discussion between the groups at risk and professionals in drawing up the action plans bring many measurable advantages. Furthermore, inventory preparation is the most important element for identifying possible solutions and preparing an implementation plan. Consequently, DWR prepared and maintained real-time stations in mountainous and flood plain areas. In addition, for crisis service, the machinery and equipment were available for crisis management in the regional offices of the Department of Water Resources.

6.1.Emergency Management Measures

During the water crisis, DWR has established the water operation center in the headquarters and the 11 regional offices for emergency management to raise awareness of residents to evaluate the scale of danger, the various methods of countering damage, and behavior during a water crisis.

7. Rehabilitation Measures

Rehabilitation and reconstruction are post-disaster measurements. Therefore, it is critical to prevent and reduce disaster risk by "Building Back Better." For example, DWR rehabilitated and reconstructed its infrastructures damaged by the disaster, such as hydraulic structures, water bodies, real-time stations, water distribution projects, and solar-powered irrigation systems.

8. Conclusions

In view of rising demand and stress on water management and climate variability, the urgent need for water resources management in agricultural and disaster management to meet future food and livelihoods is highlighted. Rainfed agriculture plays and thus will continue to play a dominant role in providing food, generating incomes, and ensuring water security. This study described the flash flood warning system, seasonal drought forecasting, and water crisis mitigation strategy in DWR's water crisis management in rainfed agriculture.

DWR installed the Early Warning System to observe rainfall and water levels in mountainous areas for flash flood monitoring and forecasting. Furthermore, the flash flood warning systems used the forecasting system and in-situ stations to clarify the flash flood risk. The results indicated that the coupling system for the flash flood warning system is adequate for implementing the actual situation in flash flood forecasting. Moreover, it substantially reduces the number of affected people from flash floods and landslides reported by the local authorities. In terms of a drought forecasting system, the water balance process was applied to determine the water deficit areas at the sub-district level in Thailand. The water supplies were evaluated by measuring all the available water in rainfall-runoff, water bodies, and watercourses. Furthermore, the water demands were calculated for domestic, agriculture, ecology, and industry sectors. The study results on water balance were in good agreement with drought areas identified by the disaster management agency, which consequently decreased the number of drought-affected areas.

DWR implemented water crisis preventive and mitigation strategies to reduce the severity of water disasters, primarily in rainfed agriculture. The measurements were taken to improve the efficiency of water resource management and reduce the impact of water disasters. Additionally, disaster management was employed to prepare the water crisis prevention and mitigation plans before, during, and after the water disaster. To begin, prevention and mitigation measures are used to reduce the loss of life and property caused by water disasters before the disaster. Therefore, the DWR considered the issues and needs of implementing a national disaster agency and the provincial offices regarding water resources information and forecasting systems. Secondly, the preparation measures for preventing and mitigating water crises consist of mitigation plans and warning systems. Thirdly, in emergency management, DWR has established the water operation center in the headquarters and the regional offices for emergency management to raise residents' awareness of evaluating the danger scale. Lastly, rehabilitation is post-disaster measurements. Consequently, it is critical to prevent and reduce disaster risk by "Building Back Better."

9. Acknowledgments

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