Engineering Journal issn: 0125-8281

*Article*

# Drought Risk Assessment of Irrigation Project Areas in a River Basin

**Tawatchai Tingsanchali**[1,*] **and Thiantheera Piriyawong**[2]

1 Asian Institute of Technology, Klong Luang, Pathumthani 12120, Thailand
2 Water Engineering and Management, Asian Institute of Technology, Klong Luang, Pathumthani12120, Thailand
*E-mail: tawatchai2593@gmail.com (Corresponding author)

**Abstract.** A model is developed for drought risk estimation in a river basin with an irrigation project. Drought risk is expressed as a product of drought hazard, exposure and vulnerability. Drought hazard is a function of rainfall, groundwater potential, groundwater quality and water storage in reservoirs. Exposure is the presence of irrigation system and crop areas inside or outside the irrigation project. Vulnerability or the lack of resistance damages due to drought depends on types of irrigation system, types of crop and their economic values. Vulnerability and exposure can be combined as consequences. The product of normalized hazard and consequences is called risk. The model is applied to assess drought risk in drought year of 2015 in the Munbon-Lamsae River Basin in Northeast Thailand. Monthly data in the past 30 years are collected. This includes rainfall, stream flow, groundwater potential and groundwater quality; and available water storage in reservoirs. Maps of hazard, consequences and risk conditions of the study area are computed in drought months such as in June 2015. The maps are calibrated for consistency with the actual field conditions by adjusting the weighting factors or coefficients of the model parameters. The developed model is further applied to estimate change in drought risk due change of irrigation system, for example when the types of irrigation system is changed from surface irrigation system to sprinkler irrigation system. The drought risk in the study area is significantly reduced because the sprinkler system can supply irrigation water more efficiently with less water loss.

**Keywords:** Drought hazard, vulnerability, exposure, risk, irrigation, Munbon-Lamsae river basin

**ENGINEERING JOURNAL** Volume 22 Issue 1
Received 14 September 2017
Accepted 28 October 2017
Published 31 January 2018
Online at http://www.engj.org/
DOI:10.4186/ej.2018.22.1.279

DOI:10.4186/ej.2018.22.1.279

## 1. Introduction

Unlike floods, droughts occur slowly and their impacts can be severe and last much longer. Only limited number of research and studies on droughts has been done in the past, therefore the present study is carried out to develop a model to assess drought hazard, drought vulnerability, exposure and drought risk. Knowing drought risk in a study area, management plan to mitigate drought impacts can be setup in advance with sufficient lead time. Both structural and non-structural measures can be implemented for the purpose of drought preparedness and according to priority setting in relation to risk assessment and actual needs of the people. The developed model is a semi-empirical model considering various factors that have influence on droughts. The model requires input data commonly available, assumed values of parameters of the semi-empirical model parameters, the model results can be verified with actual field conditions. After verification, the model can be applied to predict the change in drought risks under various scenarios for decision making on drought mitigation measures. The model can be applied to other irrigation project areas for drought risk assessment and management.

## 2. Purpose of Study

The main purpose of this study is to develop a model to determine drought hazard, exposure and vulnerability; and drought risk in a river basin with irrigation projects. Other purposes are to apply the model to a case study of Munbon-Lamsae River Basin in Northeast Thailand and to illustrate how the model can be used as a tool in decision making for drought mitigation in a river basin.

## 3. Study Area

The Munbon-Lamsae River Basin is selected as a study area as shown in Fig.1. The river basin is an upstream catchment of the Mun River Basin in Northeast Thailand. The drainage area of the Munbon-Lamsae River Basin is 2,521 km$^2$ which is a small portion of the main drainage area of 119,000 km$^2$ of the Mun River.

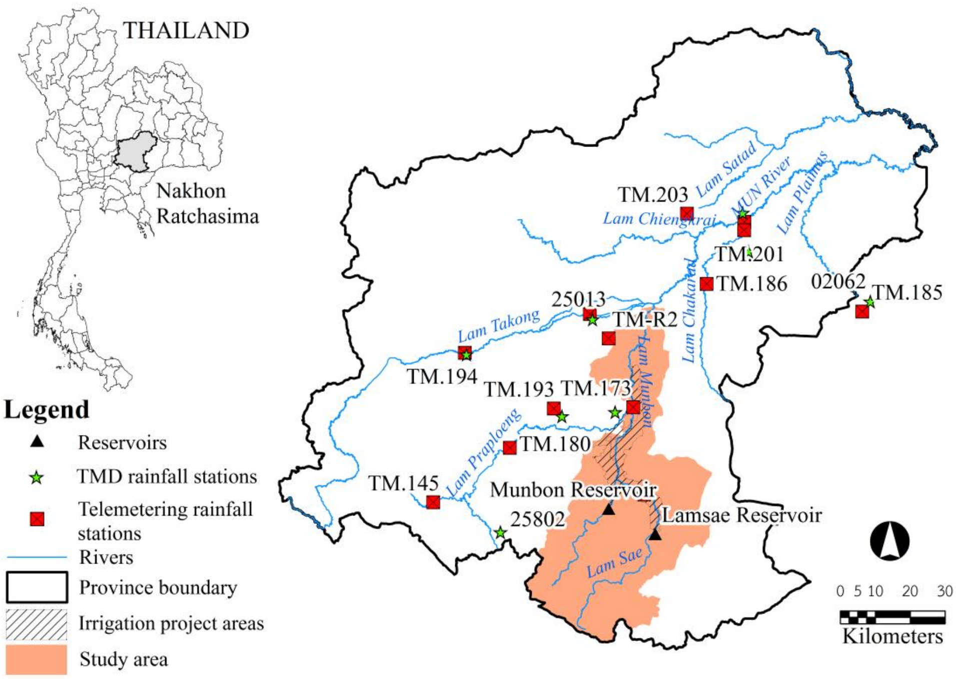


Fig. 1. Munbo-Lamsae River Basin, location of study area with two reservoirs and rainfall stations.

The Munbon-Lamsae basin mainly covers Koraburi District and Chokchai district of Nakhon Ratchasima Province. The topography of the river basin slopes downward from hilly area in the south toward the plain area in the north. The Munbon River is the main river of the river basin. It is joined by its tributary namely the Lamsae River on its way as it flows downslope before joining with its mother river: the Mun River. The overbank areas on both sides of the Munbon and Lamsae Rivers are flat near the rivers and then slowly sloping upward away from the river banks on both sides.

The Munbon-Lamsae River Basin is under the influence of tropical monsoons and tropical cyclones in which rainy season starts from mid of May to end of October. The average annual rainfall in the river basin is about 1,150 mm and annual evaporation is 1600 mm. There are two reservoirs for irrigation project of Royal Irrigation Department [1] in the river basin namely Munbon reservoir with a storage capacity of 141 MCM and Lam Sea reservoir with a storage capacity of 275 MCM. The two reservoirs supply water for irrigation project areas of 72,222 and 18,210 hectares respectively. The map showing the river basin, the rainfall stations and the irrigation project area is given in Fig. 1.

The data collected in this study includes monthly rainfall in the study area in the past 30 years; the reservoir operation data of the Munbon reservoir and the Lamsae reservoir; groundwater level and groundwater quality data; land use data; irrigation water use and type of crops, crop water requirement and crop prices.

## 4. Rainfall Deficit

Over the years, many drought indices were developed and used by meteorologists and climatologists around the world [2]. Those ranged from simple indices such as percentage of normal precipitation and precipitation percentiles to more complicated indices such as the Palmer Drought Severity Index. However, it is realized that an index needed to be simple, easy to calculate and statistically relevant and meaningful. This led to the development of Standard Precipitation Index (SPI) by Mc Kee, Doesken and Kleist (1993 and 1995) [3, 4].

SPI is used as an indicator for estimation of deficit of rainfall or precipitation on droughts. SPI is a powerful, flexible index that is simple to calculate. Due to its reliability and high efficiency, SPI has been used by National Drought Mitigation Center of U.S.A. for drought forecast and warning. SPI is calculated by using only rainfall data to indicate effect of rainfall deficit on soil moisture, stream flow, reservoir water storage, and ground water level at different time periods. In this study, 3-month SPI values are computed for drought analysis according to user guide of WMO (1992) [5] to show short term impact of rainfall deficit to drought condition.

## 5. Estimation of Drought Hazard, Exposure, Vulnerability and Risk

### 5.1. Drought Hazard

Drought hazard is the likelihood that a drought may occur. Here it is computed as a function of the weighted sum of four components by the following equation:

$$\text{Hazard} = R1.w1 + R2.w2 + R3.w3 + R4.w4 \tag{1}$$

where R1+R2+R3+R4 = 1.

The principal weights R1, R2, R3 and R4 are the weights that share the influences of the following parameters on drought hazard namely: rainfall deficit, groundwater potential, groundwater quality (Total dissolved solid: TDS) and potential shortage of reservoir water storage for crop areas inside or outside the irrigation project area respectively. The weight R1which is related to rainfall deficit is represented by Standard Precipitation Index (SPI) as described above. While the adjusting coefficients w1, w2, w3 and w4 for the weights R1, R2, R3 and R4 are considered to have the values in the range of 0 and 1. The values of R's and w's under various conditions are given in Table 1.

In this study the values of R1, R2, R3 and R4 are assumed according to the outcome of questionnaire surveys with farmers and field conditions and their values are taken to be 0.5, 0.1, 0.1 and 0.3 respectively. The weight w1 is set according to the SPI values, while the weights w2, w3 and w4 are assigned according to the variations with time and locations of groundwater level, the amount of dissolved solids in groundwater and the available water storages in the reservoirs. The range values of w1, w2, w3 and w4 are between 0 and 1 and are shown in Table 1. The computed hazard obtained from Eq. (1) over the study area is normalized between the range of its maximum and minimum values, taking the maximum equal to 1 and minimum equal to 0.

Table 1. Weights and coefficients of input parameters for estimating drought hazard and consequences.

| No. | Parameters | Weight (R) | Conditions | Coeff. (w) |
|---|---|---|---|---|
| 1 | **SPI** | **R1 = 0.50** | **Hazard** | **w1** |
| | < -2 | | Extremely dry | 1.00 |
| | -1.5 to -1.99 | | Severely dry | 0.90 |
| | -1.00 to-1.49 | | Moderate dry | 0.80 |
| | -0.01 to-0.99 | | Near normal | 0.30 |
| | > 0 | | Wet | 0.00 |
| 2 | **GW yield ($m^3$/hr.)** | **R2 = 0.10** | **Hazard** | **w2** |
| | < 2 | | Very High | 1.00 |
| | 2 -10 | | High | 0.80 |
| | 10 - 20 | | Moderate | 0.50 |
| | > 20 | | Low | 0.00 |
| 3 | **Total dissolved solid (mg/l)** | **R3 =0.10** | **Hazard** | **w3** |
| | > 1,500 | | High | 1.00 |
| | 750 - 1,500 | | Moderate | 0.30 |
| | < 750 | | Low | 0.00 |
| 4 | **Shortage of Reservoir water** | **R4 =0.30** | **Hazard** | **w4** |
| | Outside irrigation project | | High | 1.00 |
| | Inside irrigation project | | Depend on D | 1-D/100 |
| Where D = % of available water storage with the respect to reservoir full capacity | | | | |
| 5 | **Irrigation Systems** | **R5 = 0.50** | **Consequences** | **w5** |
| | Surface irrigation (furrow/border/basin) | | High | 1.00 |
| | Sprinkler | | Medium | 0.50 |
| | Drip | | Low | 0.00 |
| 6 | **Crop sensitivity to drought** [6] | **R6 = 0.25** | **Consequences** | **w6** |
| | banana, fresh green, vegetables, paddy rice, potato, sugarcane | | High | 1.00 |
| | beans, cabbage, maize, onion, peas, pepper tomato, melon | | High/ Moderate | 0.75 |
| | groundnuts, soybean, sugar beet, sunflower | | Low/ Moderate | 0.50 |
| | cassava, cotton, millet, pigeon pea, sorghum | | Low | 0.25 |
| 7 | **Crop price** | **R7 = 0.25** | **Consequences** | **w7** |
| | Sugarcane (9,000*) | | High | 0.90 |
| | Cassava (8,510*) | | High | 0.85 |
| | Corn (4,110*) | | Moderate | 0.41 |
| | Rice (3,300 *) | | Low | 0.33 |
| *Price in Baht/rai/crop; 35 Baht=1 US dollar and 1 rai = 0.16 hectare | | | | |

### 5.2. Drought Exposure and Vulnerability

According to IPPC (2012) [7] and Kron (2015) [9], exposure is the presence of people/property, vulnerability is the lack of resistance to damaging forces on human health and wellbeing; on structural or physical integrity; and on financial wealth. Vulnerability and exposure can be combined and called consequences. In this study, consequences is computed as the weighted sum of three components by the following equation

$$\text{Consequences} = \text{R5.w5} + \text{R6.w6} + \text{R7.w7} \tag{2}$$

where R5+R6+R7 = 1.

The weights R5, R6 and R7 are the weighting factors of the parameters that have influences on drought consequences namely: types of irrigation systems, crop sensitivity to drought which varies with land use area and prices of crops respectively. The coefficients w5, w6, and w7 of R5, R6 and R7 are considered to have the values within the range of 0 and 1. The values of R's and w's under various conditions are given in Table 1.

As shown in Table 1, the values of R5, R6 and R7 are assigned according to the outcome of questionnaire survey with farmers and field conditions. The values of R5, R6 and R7 are taken as 0.5, 0.25 and 0.25 respectively. The coefficients w5, w6 and w7 for the weights R5, R6 and R7 are specified according to the conditions of various types of irrigation systems, types of crops and prices of crops. The computed consequences obtained from Eq. (2) are normalized between the range of its maximum and minimum values, taking the maximum as 1 and minimum as 0.

### 5.3. Drought Risk

Drought risk is defined as the product of drought hazard and consequences [8, 9] and IPCC (2012) [7], i.e.

$$\text{Risk} = \text{Hazard x Consequences} \tag{3}$$

The hazard, consequences (vulnerability and exposure) and risk vary with locations within the study area and with time (months). Where there are no people or values that can be affected by a natural phenomenon, there is no risk. Three basic maps can be prepared to illustrate the spatial distributions of hazard, consequences and risk for each month throughout the period of study.

For relative comparison with other case studies, the computed risks obtained from Eq. (3) are normalized between the range of its maximum and minimum values, taking the maximum as 1 and minimum as 0.

## 6. Results of Model Application and Discussions

### 6.1. Drought Hazard Maps

From the computed drought hazard over the study area, a drought hazard map is developed using ArcGIS software with a pixel size of 100 m x100 m. Fig.2 shows an example of drought hazard map of the river basin for the month of June 2015, the month that has the most critical drought condition. As presented in the figure, the spatial distribution of drought hazard is classified by different color shading as low, moderate, high and very high. The regions of high drought hazard are in the area upstream of the Munbon and Lamsae reservoirs and also in the area far downstream outside the irrigation project. Where in the area of irrigation project, the hazard is mainly moderate and the hazard increases to high in the area outside the irrigation project area on both sides of the two rivers.

Far away from the river banks on both sides within the irrigation project, the hazard is moderate or low. The magnitude of hazard follows mainly the trend of rainfall deficit and to a lesser extent on availability of groundwater resources and groundwater quality.

DOI:10.4186/ej.2018.22.1.279

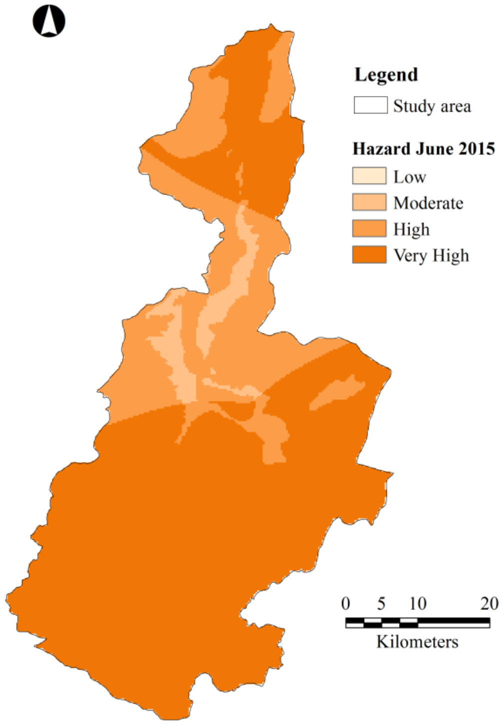


Fig. 2. Drought hazard map of the study area in June 2015

### 6.2. Drought Consequences Maps

From the computed drought consequences, the drought consequences map is developed as shown in Fig. 3 for example in the month of June 2015. The drought consequences are classified into low, moderate, high and very high. The spatial distribution of drought consequences in the river basin is shown by using different color shadings in the same figure. It can be seen that the region of highest consequences is mainly in the south eastern region of the river basin upstream of the reservoirs except in the area far upstream of the reservoirs where the area is mainly forest and there is no data on the consequences. Other areas with highest drought consequences are in the far downstream areas of the Munbon and Lamsae reservoirs outside the irrigation project areas. In the irrigation project areas, the drought consequences are low compared to the surrounding region outside the irrigation project area. For the areas along both sides of the river outside the irrigation project area, the consequences are moderate.

The magnitude of consequences follows mainly the trend of type of irrigation system and to a lesser extent on types of crops and prices of crops.

### 6.3. Drought Risk Maps

The computed drought risk in the river basin area is shown in Fig. 4. Same as in the hazard and consequences maps, the risk level is classified into low, moderate, high and very high. The risk levels are shown by using different color shadings. The highest and high drought risk areas scatter around in the regions just downstream of the dams. While in the irrigation project areas downstream of the dams, and along the both banks of the two rivers, the risk is low. The areas of moderate risk exist along the right bank of the Lamsae River downstream of the dam to the middle part of the irrigation project areas. The magnitude of drought risk is described by the products of hazard and consequences. Since there is no data on consequences in the forest area upstream of the reservoirs, hence the risk in this area is not calculated.

In view of risk mitigation, the risk can be reduced by introducing more efficient use of irrigation water such as by introducing sprinkler irrigation system to replace the existing surface water irrigation system.

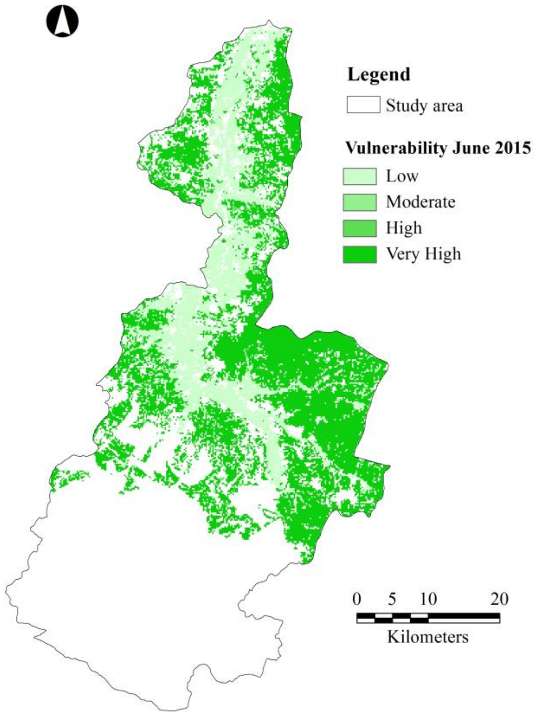


Fig. 3. Drought consequences map of the study area in June 2015.

## 7. Estimation of Drought Risk Reduction by Mitigation Measures

To show how the developed model can be applied to estimate the effect of drought mitigation measures, an investigation is carried out by considering replacing the original surface water irrigation system by the sprinkler irrigation system throughout the areas inside and outside the irrigation project. Originally the area inside the irrigation project is supplied by surface water irrigation system and the area outside the irrigation project is rain fed. Groundwater is used to supplement the irrigation water where there is a need. The main crops grown in the study area in June is cassava and sugar cane. The calculation considers the same input parameters as in the original base case except the change in irrigation system as mentioned above. The results in Fig. 5 show that the area outside the irrigation project which originally has very high or high values of consequences and risk, now has mainly moderate consequences and risk. Whereas in the area inside the irrigation project, the drought consequences and risk which are originally low remain unchanged. This is because the sprinkler system distributes water supply to crops more effectively and efficiently with less irrigation water losses.

Drought risk reduction can be done in many other ways such as change in types of irrigation system, types of crops, change in crop calendar, reservoir operation as well as supplementing irrigation supply by other alternative water resources.

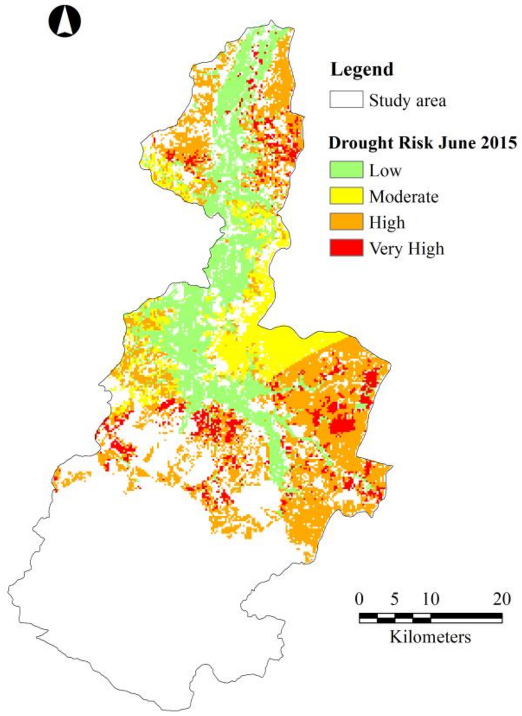


Fig. 4. Drought risk map of the study area in June 2015 under surface water irrigation system.

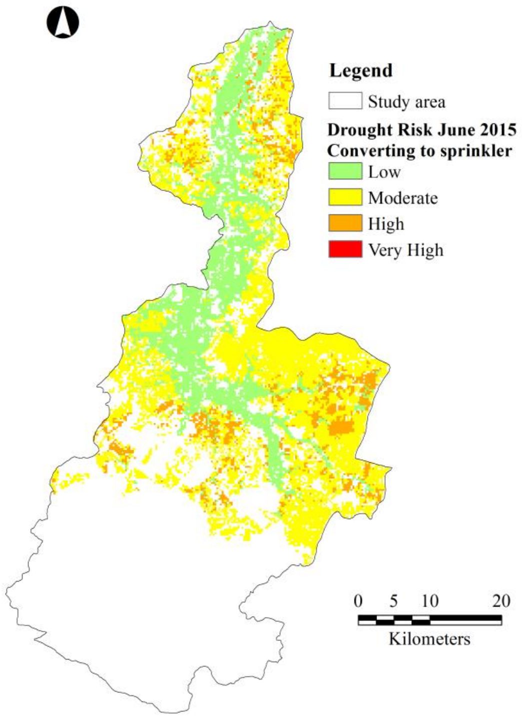


Fig. 5. Reduction in drought risk due to change of irrigation system from surface water irrigation to sprinkler irrigation system.

## 8. Conclusions and Recommendations

The study presents a model which can be used in determining drought hazard, consequences and risk in a river basin with irrigation project area. The method takes into account the effects of various input parameters such as rainfall deficit, groundwater storage, ground water quality and available reservoir water storage, etc. for hazard estimation. On consequences estimation, the method takes into account the effects of type of irrigation system, types of crop and crop prices, etc. The drought risk is computed as product hazard and consequences in which vulnerability and exposure are combined. The method can estimate change in consequences and risk due to change in the input parameters such as type of irrigation system from surface water to sprinkler irrigation. The computed drought risk is useful for setting up priority for drought preparedness plan and implementation. An example of application in this study provides a useful illustration how the model can be applied to determine reduction in drought consequences and drought risk. The model developed provides a useful decision making tool in assessing drought mitigation measures for irrigation projects in a river basin.

## References

[1] RID (Royal Irrigation Department). (2016). *Munbon and Lamsae Irrigation Project, Regional Irrigation Office 8, Thailand* [Online]. Available: http://www.rid8.go.th [Accessed: 15 December 2018]

[2] A. Ceglar, "Drought indices," Drought Management Center for Southeastern Europe, Biotechnical Faculty, University of Ljubljana, Slovenia, Report, 2008.

[3] T. B. Mc Kee, N. J. Doesken, and J. Kliest, "Drought monitoring with multiple time scales," in *Ninth Conference on Applied Climatology*, American Meteorological Society, Dallas, TX, U.S.A., 1993, pp. 233-236.

[4] T. B. Mc Kee, N. J. Doesken, and J. Kliest, "The relationship of drought frequency and duration of time scales," in *Eighth Conference on Applied Climatology*, American Meteorological Society, Anaheim, CA, U.S.A., 1995, pp.179-186.

[5] WMO (World Meteorological Organization), "Standard precipitation Index, User Guide," M. Svoboda, M. Hayes and D. Wood, Eds. World Meteorological Organization, Geneva, Switzerland, Report No. 1090, 1992.

[6] FAO (Food and Agricultural Organization), "Irrigation Water Management: Irrigation Scheduling," C. Breuwer, K. Prins, and M. Heibloem, Eds. Food and Agricultural Organization, Natural Resources Management and Environment Department, Rome, Italy, Training Manual No. 4, 1989.

[7] IPCC (Intergovernmental Panel on Climate Change), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (A Special Report of Working Groups I and II of IPCC/SREX)*, C. B. Field, V. Barros, T.F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, M. D. Mastrandrea, K. J. Mach, G. K. Plattner, S. K. Allen, M. Tignor, and P. M. Midgley, Eds. Cambridge and New York: Cambridge University Press, 2012.

[8] W. Kron, "Flood catastrophes: Causes–losses–prevention from an international re-insurer's viewpoint," in *International Workshop on Precautionary Flood Protection in Europe*, Bonn, Germany, 2003.

[9] W. Kron, "Global aspects of flood risk management," *Journal of Hydraulic Engineering*, vol. 1, pp. 35-46, 2015. doi: 10.17265/2332-8215/2015.01.004