Development of a paddy drought hazard forecasting system to cope with the impact of climate change

E Surmaini1,3, F Ramadhani1, MR Syahputra2, ER Dewi1, Y Apriyana1

1 Indonesia Agency for Agro-climate and Hydrology Research Institute, Jl. Tentara Pelajar no. 1, Bogor 16111, West Java
2 Faculty of Earth Sciences and Technology, Bandung Institute of Technology
3 Main Contributor

Email: elzasurmaini@gmail.com

Abstract. The relevance of climate extreme events, such as droughts, is well recognized as one of the impacts of climate change. The serious paddy droughts that occur during El Niño climate cycles has increased political awareness of the need to incorporate these in drought-forecasting and warning systems for effective drought management. In this study, we develop a paddy drought hazard forecasting system (PDFS) based on a web-based geographic information system (GIS). The Drought Hazard Index (DHI) was used to derive a deterministic forecast model, which is a simplified version of the probabilistic forecast model used in the previous version of this system. Based on the DHI, rice field areas in Indonesia were classified into four categories: low (1.0 < DHI < 3.3), moderate (3.33 < DHI < 6.66), high (6.66 < DHI < 10.9), and very high (10.9 < DHI < 16.0). Web-based PDFS is incorporated in the Integrated Cropping Calendar Information System (ICGIS). Predictions are available for the subsequent four months and are regularly updated every two months. The forecasts are made available for the regional areas of Indonesia at the provincial and district level.

1. Introduction

During the last few decades, drought-risk assessment and forecasting have rapidly developed in order to solve inference and decision-making problems that occur under uncertain conditions arising from climate change. As one of the world’s largest rice producers, Indonesia is concerned about agricultural drought which affects rice production yield. Agricultural drought refers to a period of declining soil moisture and subsequent crop failure without any reference to surface water resources [1]. When atmospheric moisture is reduced to the level where soil moisture is affected, the onset of an agricultural drought is imminent [2]. During this period, the livelihood of farmers, who depend on crops and livestock, is affected as the decline in soil moisture content leads to a reduction in crop production, which also affects food chain equilibrium in the ecosystem.

The Indonesian Ministry of Agriculture (MoA) reported that during El Niño years, the amount of drought-damaged paddy area in Indonesia ranges between 350,000 to 870,000 hectares [3]. Damage mostly occurs during the dry season from May-October [5]. Furthermore, crop damage is expected to increase in severity and frequency in many regions due to climate change [4].

Following the severe paddy drought during the El Niños that occurred in 1991, 1997, and 2015, there was an increase in political awareness of the need to develop adequate crop production monitoring, assessment, forecasting, and management tools [5, 6, 7]. It has been suggested that the
MoA revisit the management policy and incorporate drought forecasting and early warning systems for more effective drought management. In this study, we develop a geographic information system-based (GIS) forecast of a paddy drought hazard and delivery system that supports the preliminary steps leading to effective agricultural drought management and decision-making processes.

2. Method

2.1. Indicators of paddy drought hazard and their associated risk levels

To date, all of the various drought indices that have been developed utilize precipitation indices either separately or in combination with other meteorological variables. For example, the Standardized Precipitation Index (SPI) is commonly used to define drought that is based on timescales: SPI-1 and SPI-2 for meteorological droughts, anywhere from SPI-1 to SPI-6 for agricultural droughts, and SPI-6 to SPI-24 for hydrological droughts where the associated numbers are timescaled in months [8, 9, 10, 11].

The prototype of the forecast discussed in this paper was first developed in 2017, using SPI onset and trend as predictors [12]. The onset was characterized by the SPI-3 value three months before the drought event. The SPI-3 trend was defined by the linear regression of SPI-3 values after the onset of the drought, occurring up to the actual drought event. SPI-3 onset and trend predictions were used to predict the probability of paddy drought hazard (Figure 1). The said predictions are made available for the subsequent six months and are regularly updated every three months.1

One of the ways in which paddy drought hazards could be predicted is by organizing focus group discussions (FGD). FGDs aim to socialize the risk predictions for end-users, educating them on how to assess and interpret predictions, as well as gathering feedback. We conducted FGDs in a number of provinces in order to disseminate the paddy-drought hazard system (PDFS) that we have developed. One conclusion derived from the FGDs was that probabilistic paddy drought forecasting was difficult for extension workers and agricultural office staff to understand and interpret. Users were confused to choose which level of probability should be used in making decision. We then simplified the probabilistic forecast into a deterministic model, using the Drought Hazard Index (DHI) to make it more easily understood by end-users.

DHI is measured as the product of probability and the associated four levels of drought hazard. Using a weighting system based on the probabilities, DHI scores were assigned based on the following equation:

$$DHI = \sum_{i=1}^{4} r_i \times w_i$$

Where “$r_i$” is the probability in each drought level risk ($r_1, \ldots, r_4$) and “$w_i$” is the rating indices of the hazard level ($w_1, \ldots, w_4$). There are four different levels of drought: low, moderate, high, and very high. Each level has its own probability value, which was assigned using the quadratic method. In this paper, we used 1, 4, 9, 16 ($1^2, 2^2, 3^2$ and $4^2$) as rating indices.

1The predictions may be accessed from the Indonesian Agro-climate and Hydrology Research Institute (IAHRI)’s website http://balitklimat.litbang.pertanian.go.id/.
Figure 1. Spatial distribution of SPI-3 onset and SPI-3 trend were used to generate an operational DHI forecasting map.

2.2. Paddy-drought-hazard-forecasting map

To simplify the drought hazard levels, probabilistic forecast data was converted into deterministic forecast data using the DHI quadratic interval method. We calculated the DHI values for each of the grid areas in Indonesia and classified them into four hazard levels as seen in Table 1.

| DHI   | Hazard Level | Category |
|-------|--------------|----------|
| 1.0-3.3 | I            | Low      |
| 3.3-6.6 | II           | Moderate |
| 6.6-10.9 | III          | High     |
| 10.9-16.0 | IV          | Very high|

The DHI prediction map was then overlaid with the agricultural map to produce a deterministic paddy drought hazard prediction map. The flowchart is shown in Figure 2.

Figure 2. Flowchart for converting a probabilistic to a deterministic model of the paddy drought hazard map.
2.3. A web-based paddy drought hazard forecasting system
A web-based application similar to that used in [13] was used to deliver the information so that users can easily access the forecast from any computer connected to the internet using a standard browser. The application can be accessed via http://katam.litbang.pertanian.go.id/.

3. Results and Discussion
3.1. Level of Drought Hazard Index
Based on the calculated DHIs, rice field areas in Indonesia were classified into four categories: low (1.0 < DHI < 3.3), moderate (3.33 < DHI < 6.66), high (6.66 < DHI < 10.9), and very high (10.9 < DHI < 16.0). An example of DHI level analysis is shown in Table 2.

Table 2. Example of calculation level of DHI

| Drought hazard level | Probability (w) | Rating (r) | DHI Level (DHI) = w x r |
|----------------------|-----------------|------------|----------------------|
| 1 (low)              | 60%             | 1          | 0.6                  |
| 2 (moderate)         | 30%             | 4          | 1.2                  |
| 3 (high)             | 10%             | 9          | 0.8                  |
| 4 (very high)        | 0%              | 16         | 0                    |

DHI Level

3.2. Paddy-drought-hazard forecasting map
The conversion of drought hazard levels using DHI makes it easier to understand for end users than the previous probabilistic model. The conversion of drought classification and overlays for the paddy drought hazard map are shown in Figure 3.

Figure 3. Generation of the paddy drought forecasting map. A drought hazard map using a quadratic interval (A) was classified into a four-level DHI map (B), which was then overlaid with a rice field map in order to produce the PDFS map (C). The status of PDFS is shown on four regional levels using a color code: low (green), moderate (yellow), high (red), and very high (violet).
An example of comparison between the probabilistic and deterministic prediction maps after the overlay of the rice field map is shown in Figure 4. The probabilistic map shows a spectrum of colors (probability) for each risk level; whereas the deterministic map shows only a single color denoting each risk level, thereby simplifying the means of interpretation for end users.

![Figure 4. Comparison of probabilistic and deterministic paddy drought hazard forecasting maps](image1)

3.3. The web-based PDFS

The web-based PDFS in this paper was developed so that information could be delivered instantly and directly to end users [14]. The forecast is made available for the subsequent four months and regularly updated every two months. The web-based PDFS system is incorporated in the Integrated Cropping Calendar Information System and can be accessed at [http://katam.litbang.pertanian.go.id/](http://katam.litbang.pertanian.go.id/).

![Figure 5. Screenshot of the home page of the interactive the web-based PDFS (top) and how to access the maps in pdf file (bottom).](image2)
Monthly forecasts are also available for regional areas of Indonesia at the provincial and district levels. For example, three-month predictions for Langkat District, North Sumatera are shown in Figure 6. High risk areas more prone to drought occurrences are shown in hues of red. Detailed sub-Districts were predicted to experience moderate and high drought risk in September-November 2019 are described in Table 3.

![Paddy-drought-forecasting maps for September–November, 2019 for Langkat District, North Sumatra accessed from http://katam.litbang.pertanian.go.id/](image)

**Figure 6.** Paddy-drought-forecasting maps for September–November, 2019 for Langkat District, North Sumatra accessed from http://katam.litbang.pertanian.go.id/

**Table 3.** Sub-Districts in Langkat District which are predicted to experience moderate and high drought risk in September-November 2019

| Month   | Moderate-risk              | High-risk       |
|---------|----------------------------|-----------------|
| September | Pematang Raya, Pangkalan Susu, Besitang, Secangkang | - |
| October  | Gebang, Tanjung Raya, Hinai, Stabat, Wampu, Babalan, Sei Lapan, Binjai, Selesa, Sirapat, Bohorok | Pematang Raya, Pangkalan Susu, Besitang, Secangkang |
| November | Pematang Raya, Pangkalan Susu, Besitang, Secangkang, Brandan Barat, Gebang, Tanjung Pura, Hinai, Stabat, | - |

4. Conclusion
The PDFS offers new information for preparedness and mitigation planning for paddy drought in Indonesia that permits integrated use of meteorological and agronomic data. The new version was simplified from a probabilistic to deterministic forecast using the DHI. Based on the DHI, paddy drought hazards were classified into four categories: low, moderate, high, and very high. The predictions are available for the subsequent four months and regularly updated every two months. The web-based-paddy-drought forecasting was incorporated in Integrated Cropping Calendar Information System. This system can be used to prepare for drought conditions onways of mitigating droughts. It is expected that decision makers are able to determine drought responses; thereby improving the quality of decision-making and increasing the effectiveness of drought management.

Acknowledgments
This work was supporting by a grand (31.12/PL.040/H.1/02/2018.K) from The Indonesian Agency for Agricultural Research and Development
References

[1] Mishra A., Singh VP 2010 A review of drought concepts J. Hydrol 391 202–216.

[2] Zargar A, Sadiq R, Naser B, Khan FI 2011 A review of drought indices Environ. Rev 19 333–49

[3] Surmaini E, Hadi TW, Subagyono K, Puspito NT 2015 Early detection of drought impact on rice paddies in Indonesia Theor. Appl. Climatol 121 669-84.

[4] IPCC 2012 Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of WG I and II of the Intergovernmental Panel on Climate Change ed CB Field et al. (Cambridge University Press, Cambridge, UK)

[5] Horion S, Carrão H, Singleton A, Barbosa P, Vogt J 2012 JRC experience in the development of Drought Information Systems. Europe, Africa and Latin America (Publications Office of the European Union)

[6] Sheffield J, Wood EF, Chaney N, et al. 2014 A drought monitoring and forecasting system for Sub-Saharan African water resources and food security Bull. Am. Meteorol. Soc. 95 861–82.

[7] Svoboda MD, Fuchs BA, Poulsen CC, Nothwehr JR 2015 The drought risk atlas: enhancing decision support for drought risk management in the United States J. Hydrol. 526 274–86.

[8] WMO 2010 Guidelines on early warning systems and application of now-casting and warning operations. WMO/TD No 1559

[9] Tatli H 2015 Downscaling standardized precipitation index via model output statistics. Atmosfera 28 83–98

[10] Meng L, Ford T, Guo Y 2016 Logistic regression analysis of drought persistence in East China. Int. J. Climatol 37 1444–1455

[11] Sohn S.J, Tam CY 2016 Long-lead station-scale prediction of hydrological droughts in South Korea based on bivariate pattern-based downscaling Clim. Dyn. 46 3305–21

[12] Surmaini E, Susanti E, Syahputra MR, Hadi TW 2019 Exploring Standardized Precipitation Index for predicting drought in rice paddies in Indonesia IOP Conf. Ser.: Earth Environ. Sci. 303 012027

[13] Ramadhani F, Runtuwu E, Syahbuddin H 2013 Sistem Teknologi Informasi Kalender TanamTerpadu. Informatika Pertanian, 22 (2) 103-12

[14] UNISDR 2009 Terminology on Disaster Risk Reduction. UN Secretariat of the International Strategy for Disaster Reduction (UNISDR Geneva, Switzerland)