Projecting and managing hydrological drought in Indonesia

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Abstract. Indonesia identifies as climate change hotspots and indicates to have increasing hydrological drought risk. The impact of hydrological drought is easier to analyze because only using river discharge directly affects by rain, which requires a long process and time. The impact of hydrological drought can be minimized using Disaster Risk Management (DRM) cycle. In this study, Standardized Runoff Index (SRI) was used as a quantitative index for the occurrence of hydrological drought and as a reference for phase change in DRM. This study consists of 3 parts: projecting monthly discharge until the year of 2045 using ensemble of seven Global Climate Models; projecting hydrological drought events using SRI; and suggesting six DRM stages for managing its impact. The study took case on Pawan River Basin, West Kalimantan. Kalimantan is predicted to be experienced more extreme dry climate in Indonesia. The potential for drought (Q80) is projected to be more severe in the range of January to July (-4% to -11%) and October (-3% to -5%) on the Pawan River Basin. DRM is divided into six phases: risk assessment, risk prevention, risk mitigation, preparedness for the occurrence, response to disaster and recovery.

1. Introduction
Indonesia is known as one of the world’s most disaster-prone countries, including drought. According to a report from CRED in 2017 Indonesia has the highest number of deaths due to drought during 1987-2016. Out of a total of 691 victims in ASEAN, 683 are said from Indonesia [1]. The effects of drought also play a large role in local communities and damage to crops and drinking water supply. In Indramayu, West Java, in 2002, drought happened due to El Nino and caused huge losses. The number of families living below the poverty line increased from 55% to 64% in just a year caused by drought, followed by crop failure accompanied by rising food and fuel prices. In Lombok and Sumbawa islands, between 1985 and 2006, the number of water sources for irrigation and drinking water fell from 580 to 180. Drought also leads to other disasters. As in El Niño 1997, the total area of fire-damaged peatland in Indonesia is estimated at 6.8 million ha. These fires have caused health problems and damaged people’s livelihoods–increasing poverty rates by one-third or more. Crop failures in 2002 and 2005 caused malnutrition cases in Belu district, Nusa Tenggara Timur is widespread across the province – between 32 and 50 percent [2].

On the other hand, Indonesia is identified as climate change hotspots, indicating that the climate change scenarios indicate increasing drought risk in the IPCC 4th assessment report. These extreme climatic events have become more frequent in recent years, and their impact has been more severe. Between 1844 and 1960, droughts happened on average every four years, but between 1961 and 2006, they occurred every three years [2]. According to Kementerian PPN [3], in 2020-2025, it is predicted that extreme dry climates will more likely happen in large parts of Indonesia (Sumatera, Kalimantan and
Papua). The water crisis area is estimated to increase from 6.0% (2000) to 9.6% (2045). Water quality is also estimated to decrease significantly.

Although drought may seem to be the most frequent and influential natural disaster within the ASEAN region, the consequences of drought events might be underestimated due to droughts’ unrecorded impacts. The creeping nature of droughts can hinder sensing its onsets and termination [4]. Drought impacts may linger even after the termination of a drought event [5]. Thus, there are likely unrecorded damages from past droughts across ASEAN region. It should be noted that drought can limit water resources and energy generation in ASEAN countries. Low water availability and high temperature of cooling water can limit energy generation in all types of power plants, thus significantly impairing human livelihood. Damages from the chain effects of precipitation deficiency may be missing from the disaster statistic [1].

Hydrological drought is a drought associated with the effects of lack of rainfall periods on water availability in rivers, reservoirs, lakes, and groundwater. The impact of hydrological drought is easier for analyzing, especially its impact on water infrastructure, because it uses a river flow variable that has a direct effect compared to rain, which still requires a long process and time. One of the hydrological drought indices that is often used is Standardized Runoff Index (SRI). SRI only requires monthly discharge data at the study location. In this research, SRI will be used as an indicator in determining the processes and phases in hydrological drought, then Disaster Risk Management (DRM) stages will be made to overcome hydrological drought.

2. Data and methods
Climate change impact on rainfall was projected using Representative Concentration Pathways (RCP) 8.5 of Global Climate Model (GCM). It assumes a high population and relatively slow income growth with modest technological change rates and energy intensity improvements. It leads in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall was projected until the year 2045 using ensemble of seven models (CNRM CM5, CNRM RCA, CNRM v2 RegCM, CSIRO MK3.6, EC EARTH, GFDL ESM and IPSL). Data were divided into two groups: baseline periods (1981-2005) and the projection period (2006-2045). For the rainfall projection period from 2006 to 2045, a statistical bias correction using quantile mapping methods was applied. Quantile mapping is proved to give best results in annual maximum hydrological simulations compared to other bias correction methods [6] and the most efficient in removing rainfall bias compared with several downscaling approaches [7]. We used CHIRPS dataset as observation rainfall data. CHIRPS data has high resolution and long data sequences to cover blank areas, disconnected data and data inconsistencies in Indonesia area [8]. SRI is calculated using the gamma distribution.

\[
SRI = -\left( t - \frac{2.515 + 0.802 t + 0.010 t^2}{1 + 1.432 t + 0.189 t^2 + 0.001 t^3} \right) \quad \text{for} \ 0 < H(x) \leq 0.5
\]  
(1)

\[
SRI = +\left( t - \frac{2.515 + 0.802 t + 0.010 t^2}{1 + 1.432 t + 0.189 t^2 + 0.001 t^3} \right) \quad \text{for} \ 0.5 < H(x) \leq 1.0
\]  
(2)

\[
t = \sqrt{\ln\left( \frac{1}{(H(x))^2} \right)} \quad \text{for} \ 0 < H(x) \leq 0.5
\]  
(3)

\[
t = \sqrt{\ln\left( \frac{1}{(1.0 - H(x))^2} \right)} \quad \text{for} \ 0.5 < H(x) \leq 1.0
\]  
(4)

SRI values indicate the study area’s hydrological conditions with the classification of the value ranges in Table 1.
Table 1. Drought classification based on SRI value

| SRI Value | Classification   |
|-----------|------------------|
| ≥ 2.0     | Extremely wet    |
| 1.5 to 1.9| Severely wet     |
| 1.0 to 1.4| Moderate wet     |
| -1.0 to 1.0| Normal          |
| -1.5 to -1.0| Moderate dry   |
| -1.9 to -1.5| Severely dry   |
| ≤ -2.0   | Extremely dry    |

Disaster risk management (DRM) is a permanent process of analyzing, planning, decision-making and implementing a diversity of measures to (a) identify, prevent and reduce the possibility of disasters occurring, (b) respond appropriately should one occur and (c) recover livelihoods, services and systems following any such occurrence [9]. DRM in managing hydrological drought will be represented in six components: risk assessment, risk prevention, risk mitigation, preparedness for the occurrence of disasters, response to disaster and recovery.

In DRM, hydrological drought and its relationship with SRI are explained in Figure 1, where the stages of risk assessment, risk prevention and risk mitigation are in wet to normal conditions (SRI values greater than -0.5). While at the stage of preparedness for the occurrence of disasters is defined as actions that need to be taken before a hydrological drought occurs (SRI value between -0.5 to -1.0, conditions are quite dry). The response to disaster phase is defined as the DRM action taken when a hydrological drought has occurred (SRI value less than -1.0 or drought to extremely dry) and the recovery stage is defined as the DRM stage that needs to be carried out after the drought event has occurred (SRI is worth more from 0.5/ normal event).

3. Results and discussion

3.1. Projecting discharge
Using seven models of climate change rainfall scenario model, monthly discharge projections were carried out until 2045. Checking the projection results in the control period needs to be done to find out how big the difference between projected discharge to the actual discharge value.
Figure 2 shows discharge projections’ results using seven ensemble models that tend to overestimate at high discharges (above Q30). The Q50, Q80 and Q90 discharge the projected discharge are quite close to the observation discharge. It can be said that the results of discharge projection can be used for the analysis of average and low discharge. For next analysis, the mean of seven ensembles models is used as the projected discharge.

### Table 2. Mean Monthly Projected Q80 on Pawan River Basin During in 2006-2045

| Month | 2006-2015 | 2016-2025 | 2026-2035 | 2036-2045 |
|-------|-----------|-----------|-----------|-----------|
| Jan   | 55.9      | 52.3      | 50.8      | 49.2      |
| Feb   | 42.6      | 46.2      | 40.7      | 44.6      |
| Mar   | 46.9      | 45.2      | 50.7      | 41.8      |
| Apr   | 49.4      | 43.9      | 47.0      | 50.2      |
| May   | 45.0      | 39.5      | 42.7      | 46.3      |
| Jun   | 23.6      | 23.5      | 22.5      | 24.1      |
| Jul   | 27.6      | 24.6      | 26.6      | 27.7      |
| Aug   | 27.7      | 28.8      | 29.6      | 30.4      |
| Sep   | 30.3      | 30.8      | 31.2      | 29.8      |
| Oct   | 37.1      | 39.4      | 36.0      | 35.4      |
| Nov   | 34.0      | 39.7      | 38.4      | 34.4      |
| Dec   | 56.5      | 49.4      | 55.8      | 56.3      |

Q80 discharge on Pawan River Basin per decade is projected to decline gradually. From January to March, it is shown a decrease of -4% to -9% in 2026-2035 and -12% to in 2036-3045. In April to July, it decreases by -4% to -5% (2026-2035) and 0% to -11% (2036-2045), while in October it ranged from -3% to -5% in the same two decades. The decline in the value of Q80 is not much seen in December. The potential for drought is projected to be more severe in the range of January to July and September on the Pawan River Basin.

3.2. Projecting hydrological drought

The hydrological drought index calculation using the SRI method is carried out on 1, 3, 6, 9, and 12 months’ time scales by using projected monthly discharge. Figure 3 shows that generally, the severity of hydrological drought is still in the near normal to dry on all time scales severely.
SRI-1 shows a discharge deficit in one month, while SRI-3 shows a deficit in the accumulation of the last three months and SRI-6, SRI-9, and SRI-12. If the SRI-1 value is less than 2 or in extremely dry condition, extreme drought will occur in a short notice and in severe duration because it is caused by one-month discharge deficit only. Whereas if SRI-12 shows a value of less than 2, this indicates extreme drought will occur in a long time because it accumulates the previous 12 months. This case can be seen in November 2011, where a long drought is projected because SRI-12 shows extremely drought phase, while SRI-1 has shown that phase from January 2011. This also occurred in January 2021 to December 2021, which projected long periods of indirect but slowly extreme drought, by SRI-12 showing a phase of severe drought in June 2021. This is different from January 2016, June 2026, October 2027, February 2029, and December 2034, where SRI-1 to SRI-3 shows a phase of extreme drought but not SRI-12, which indicates sudden drought short but extreme duration.

3.3. Managing hydrological drought
The impact of hydrological drought can be minimized by using DRM cycle. In this study, SRI is used as a quantitative index for drought and as a reference for phase change in DRM. DRM is divided into six phases: risk assessment, risk prevention, risk mitigation, preparedness for the occurrence of disasters, response to disaster and recovery.

3.3.1. Risk assessment. Risk assessment is the first step in mitigating disaster. We suggest updating hydrological data, improving data quality, updating recent water infrastructures and planning, collecting projections on socioeconomic conditions, identifying groups at drought risk, analyzing drought occurrence and severity, assess climate change impacts on drought risk, and archiving past drought events and their consequences. Research on extreme weather and hydrometeorological disasters needs to be carried out more frequently and interrelated with each other. It is necessary to archive rainfall data and events that occur in related locations for collecting data. The rainfall data available in Indonesia are relatively few compared with its large [10]. This can be anticipated temporarily with satellite reanalysis data such as Tropical Rainfall Measuring Mission (TRMM), Global Satellite Mapping of Precipitation (GSMaP), dan Climate Hazard Group InfraRed Precipitation with Station (CHIRPS). These data must be processed in spatial form. GIS-based systems can be used effectively to manage natural and human-made disasters. When combined with a 3D spatially oriented database, rapid and detailed disaster assessments can facilitate the limitations of traditional tools previously rendered impossible [11].

3.3.2. Risk prevention. Risk prevention is actions that, if taken, would keep the disaster from happening at all. Prevention of drought divided into two parts, improving water use and improving access to water supply.
Improving water use efficiency in irrigation, drinking water production, and hydropower infrastructure by using integrated water resources management. Using integrated water resources management, water resources can be monitored in real-time both in terms of water availability and water needs at each spatial and temporal point. Spatial and real-time water management will also facilitate stakeholders in water use planning and reduce conflicts of interest between. From the side of agriculture itself, innovation about crop varieties that are more resilient to climate change is also needed. Examples such as ‘gogo’-type rice tend to need less water than rice varieties in general, although further development is needed so that the quality of varieties is also similar or even better than ordinary varieties. Planting techniques such as the System of Rice Intensification in rice have also been proven to minimize crop failure due to low rainfall and inadequate irrigation water. Innovations in plant varieties and planting techniques.

Improving access to water supply by reducing Non-Revenue Water (NRW) and developing water resources other than surface water such as Rain Water Harvesting (RWH), seawater desalination, and water recycling. BPPSPAM [12] mentioned that there are several efforts to reduce NRW, namely to immediately repair visible or reported leaks, update the pipeline network map, utilize leak detection equipment that has not been used, update customer databases, find illegal connections routinely and replace customer water meters especially those aged over 5 years. Whereas RWH can be used as a rainwater reservoir to later be used during the dry season and as a rainwater reservoir that is then processed so that the rainwater quality is higher like raw water. RWH can also save energy use and reduce carbon emissions. The construction of dams and reservoirs also helps prevent hydrological drought. There is also more advanced technology in water harvesting called ABSAH (Akuifer Buantan Simpanan Air Hujan, Artificial Aquifer of Rain Water Deposit). ABSAH is the development and modification of a PAH (Penampung Air Hujan, Rainwater Collection) building made of concrete, used rainwater in the building on the roof of the building, which then flowed into an artificial aquifer (groundwater layer) and finally accommodated in a water storage tank (reservoir) [13].

In water recycling, the main problem is the limited use of recycled water due to consumer distrust of processed water. Recycled products are only used in washing and flushing toilets. This then causes only a small amount of water to be recycled, resulting in small recycling water efficiency. It is expected that research on water recycling can continue faster to gain consumer trust in the processed water. While the obstacle in desalinizing seawater into ready-to-consume water is the high cost of production, research on economical desalination is highly anticipated. It is highly anticipated that sea water’s huge potential with almost 6,000 times the amount of surface water.

3.3.3. Risk mitigation. Risk mitigation aims to reduce the disaster's impact, while prevention is focused on stopping the disaster from happening. The effects of drought tend not to directly impact infrastructure, in contrast to other disasters big effects such as floods or tsunamis. This indeed makes it difficult to quantify the effects of drought. In drought mitigation, it tends to focus on the early warning system from seasonal meteorological forecast to its delivery systems to the affected communities. Weather prediction in Indonesia with accurate results is still difficult because the topography and climate system tend to be mostly influenced by local factors. Reservoir and dam operational systems that are responsive to weather conditions are also needed to minimize downstream water deficits. Mapping drought risks, hazards, exposure and vulnerability, is also needed to prevent other disasters that occur due to drought, such as forest fires, crop failures, water shortages that can cause electricity deficits if there is hydropower at that location. In addition, development programs and training programs at both national and sub-national levels are needed, especially for severe drought events. Community disaster planning would make drought mitigation more effective, with responsive communities knowing what should be done when a drought occurs.

3.3.4. Preparedness for the occurrence of disasters and response to disaster. Before hydrological drought occurred, anticipation steps that need to be taken are steps to minimize other disasters that occur due to drought. Real time monitoring of water shortage in water infrastructures such as the intake point
of hydropower, raw water, drinking water, and irrigation needs to be carried out continuously. Furthermore, monitoring at groundwater level, reservoir storage, irrigation demand, and hydroelectric production demand also need to be done. For areas prone to severe drought impacts, such as forest fires and crop failure prone, they should be given more attention. In areas prone to forest fires, zoning of fire-prone areas is needed (both from the hydrological index and aspects of vegetation, soil, geology, topography), identifying hotspot monitoring with sensory or terrestrial imagery, and management of forest areas to minimize fires triggered by human activity. Whereas in areas prone to crop failure, actions such as encouraging the use of plants suitable for dry conditions and water pump assistance are expected to prevent crop failure during the dry season. In addition, technologies such as Weather Modification Technology in the form of seeding clouds to initiate rain can also be an option in the stages leading up to the drought. Groundwater can also be an option as an additional source of water when river water is insufficient, concerning its limit. Estimation of the groundwater uptake limit can be determined through baseflow recession method.

3.3.5. Recovery. Recovery stages start when SRI value entering the normal phase. Recovery stages should include recovery act for reconstruction, economy, health and social factor [14]. Normalization of conditions and problems caused by drought, such as crop failure, forest fires, energy deficits, need to be done. Therefore, it is necessary to stabilize prices and amount of the yields, clean water supports, and energy deficits supports in affected locations in the short term. The operational simulation rule (“pola operasi”) and Standard Operating Procedures in reservoirs and other water infrastructure should have a scheme when dry conditions occur. In addition, conservation of catchment areas also needs to be done to minimize future drought.

4. Conclusions
Indonesia is identified as climate change hotspots, indicating that climate change scenarios indicate increasing drought risk. Kalimantan is predicted to be experienced more extreme dry climate in Indonesia. In this study, it is projected that the potential for drought on Pawan River Basin, West Kalimantan. The potential for drought (Q80) is projected to be more severe in the range of January to July (-4% to -11%) and October (-3% to -5%) on the Pawan River Basin. From January 2021 to December 2021, it is projected there will be long periods of indirect but slowly extreme drought. In June 2026, October 2027, February 2029, and December 2034, the SRI values indicate sudden drought in a short period but extreme intensity. Seeing the increase in hydrological drought intensity and frequency in Indonesia’s river basin, we suggest a DRM based on SRI indicator to overcome hydrological drought.

DRM for hydrological drought is divided into six phases: risk assessment, risk prevention, risk mitigation, preparedness for the occurrence of disasters, response to disaster, and recovery. The stages of risk assessment, risk prevention, and risk mitigation are in wet to normal conditions. At the stage of preparedness, disasters are defined as actions that need to be taken before a hydrological drought. The response to disaster phase is defined as the DRM action taken when a hydrological drought has occurred and the recovery stage is defined as the DRM stage that needs to be carried out after the drought event has occurred.

In risk assessment, we suggest updating hydrological data, improving data quality, identifying groups at drought risk, analyzing drought occurrence and severity and assess climate change impacts on drought risk. These data must be processed in spatial form. In risk prevention, we suggest to improve water use efficiency and improve access to water supply. In drought mitigation, we suggest focusing on the early warning system, mapping drought risks, and continuously monitoring water shortage in water infrastructure. We suggest mapping and zone areas prone to forest fires and crop failure for preparedness for the occurrence of disaster. While in response to disaster phase, we suggest preparing technology such as Weather Modification Technology. Groundwater can also be an option as an additional source of water when river water is insufficient, concerning its limit. The least, the recovery stages should include recovery act for reconstruction, economy, health, and social factor of the area. The operational simulation rule (“pola operasi”) and Standard Operating Procedures both in reservoirs and other water infrastructure should have a scheme when dry conditions occur.
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