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RESEARCH ARTICLE

State-of-the-Art Drought Handling in Indonesia

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Abstract Droughts tend to become more extreme, longer, and more frequent as an impact of climate change. Droughts now impact various development activities, especially those reliant on water resources, like agriculture for food security. Drought management issues in Indonesia stem from inadequate regulations and laws regarding drought response, due to intricate agency procedures and overlapping responsibilities. Nevertheless, there are currently established partial regulations and laws that govern the management of meteorological data and the accessibility of water resources. Without clear rules, policies, and frameworks, government policies on drought become less effective and overlapping. The research and novelty aim to design an integrated framework for handling drought by examining the present circumstances of relevant agencies using spatial nexus framework that is divided into three stages (construction, deconstruction, and reconstruction). During the first stage, the focus goes toward developing the construction framework will be proposed. The construction framework was conducted descriptively through a desk research method of drought management public policies, institutions, and operating systems for the agricultural sector in Indonesia. Moreover, a panel discussion was held to obtain the data and information about drought management by the government. Field observations were conducted to determine the handling of water resources practically for agriculture. Thus, drought management has been more concentrated on meteorological/climatological and hydrological elements. Moreover, it focuses on the statistical results of public and agricultural activities rather than on their socioeconomic consequences. A spatial approach will become the integration node of meteorological/hydrological elements, socioeconomic components, and agricultural activities.

1. Introduction

Drought is a natural hazard as a consequence of broad climatic volatility that cannot be avoided by local water management (Van Loon, 2015). The phenomenon's intricacy, as well as its difficulty to identify spatial and temporal limits, hinders the creation of a universally accepted definition. Drought occurrences, in their most basic form, reflect a water deficit relative to normal conditions (Lloyd-Hughes, 2014). Drought has to be defined operationally in addition to conceptually. This operational definition will be used to build preventative and mitigation methods and will allow us to identify the occurrence and describe its frequency, intensity, and duration for a specific return period (Mishra & Singh, 2010). Drought is frequently associated with disaster and natural hazards despite its rarely the end in a state of emergency. Nonetheless, its effects might result in an emergency state if it happens in high vulnerability (Raikes et al., 2019). Drought can occur in almost any climate zone, such as areas with high or low rainfall, and it mainly expresses a reduction in the amount of rainfall experienced over seasons or years. Drought has had the most detrimental impact of any natural hazard in the twentieth century (Bruce, 1994; Obasi, 1994). It has broad implications, affecting not just agriculture but also water resources, food security, energy, forestry, transportation, and other resources. According to this investigation, drought contributes the largest proportion of total losses in the United States after tropical cyclones (Smith & Matthews, 2015). One of the most important implications is the impact on food security. Understanding the relationship between drought and food security is crucial for mitigating the effects of a drought hazard.

The worldwide food security situation is deteriorating due to the failure of numerous food production processes to generate sustainable food production because of drought (2020). Despite the fact that other, no less significant factors have exacerbated the Pacific region's food insecurity as a result of the COVID-19 crisis (2022) (Wang et al., 2020). GFSI for Indonesia in 2022 was 60.2 on a scale of 0-100. The stronger the food security, the higher the index. The highest GFSI for the previous five years was 63.6 in 2018, based on the Food Security Bureau Republic of Indonesia in 2022. Similar to other developing countries, Indonesia has a long history of food security problems. Food availability, food accessibility, and food stability are the three key components of food security. Drought, particularly the ENZO effect, is the most significant

Table of Abbreviations

BBWS	River Basin Agency
BMKG	Meteorology Climatology and Geophysics Agency
BNPB	National Disaster Management Agency
BRIN	National Research and Innovation Agency
ENZO	El Niño Southern Oscillation
EVI	Enhanced Vegetation Index
EWS	Early Warning System
FAO	Food and Agriculture Organization
GFSI	Global Food Security Index
IAARD	Indonesian Agency for Agricultural Research and Development
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
IPWP	Indo Pacific Warm Pool
LAPAN	National Institute of Aeronautics and Space
LPDP	Indonesia Endowment Fund for Education
MoA	Ministry of Agriculture
MoEF	Ministry of Environment and Forestry
MoPWH	Ministry of Public Works and Housing
MoRT/NRIA	Ministry of Research and Technology/National Research and Innovation Agency
NDVI	Normalized Difference Vegetation Index
PRN	National Research Priority
SADEWA	Satellite-Based Disaster Early Warning System
SPI	Standardized Precipitation Index
SST	Sea Surface Temperature
WFP	World Food Programme
WMO	World Meteorological Organization

influence on this problem in Indonesia besides the high rate of population growth (Falcon et al., 2004; Rozaki, 2021). They examined the fact that a one-degree Celsius increase in SST contributes to a one-million-metric-ton decrease in national rice production, the majority of which occurs on Java Island during 1997 - 2002. Several proposals have been proposed for food security handling, including modeling and forecasting using climate data, annual global summits, and annual achievement (Falcon et al., 2004). This research also proposes food security management related to climate change in South Asia, including the development of a national disaster management strategy (Douglas, 2009). They divided strategies at the international, national, local, and individual levels into proactive and reactive approaches. For instance, proactive is defined as incorporating care of a drought risk situation before a drought occurs, instead of reacting to a drought after it occurred and hit a crisis level. The proactive national responses include enhancing drainage, supplying food stocks, and coordinating government agencies to prevent disasters. While the reactive national responses are to stabilize prices and rebuild embankments and water systems in emergency situations as well.

In recent years, large-scale, acute drought has been recorded on all continents (Le Comte, 1994). Droughts have occurred in Australia (2000–2009), the United States (2000–2016), South and Sub-Saharan Africa (2015–2017), China (2007–2012), and Europe (2007–2010) (Ault et al., 2016; Baudoin et al., 2017; Chao et al., 2016; Cook et al., 2016; Ummenhofer et al., 2009). Several techniques, including the drought risk index and risk mapping, have been utilized to manage the drought in Australia. They constructed a risk mapping by determining the drought risk index of the local or district area level, which includes hazard, vulnerability, and exposure indices. Policies have been made and implemented with stringent controls and monitoring in near real-time. A criterion-based ranking has been determined to generate a quantitative efficacy and responsiveness ranking for each major drought indicator index (Aitkenhead et al., 2021). Other previous research suggested drought forecasting and early warning systems to reduce the impact of drought (Raikes et al., 2019). This research suggested two types of management frameworks used to deal with drought: risk management (Wilhite et al., 2014) and crisis management (Durley & de Loë, 2005; Fu et al., 2013). Where risk management is more focused on disaster prevention models and potential effect mitigation before and after a drought disaster. Meanwhile, crisis management is a reactive management style that emphasizes action when a drought occurs (Wilhite et al., 2000).

As a framework, crisis management is utilized around 80% more frequently than risk management. Crisis management is used in 32 of the 44 US states rather than risk management (Fu et al., 2013). Drought management is frequently lacking in efficient water infrastructure and early warning systems. They tend to emphasize drought response and disaster relief (Wilhite et al., 2014). Because drought has gradually commenced, most drought management is ineffective and always late. Typically, drought conditions are merely regarded as a usual natural occurrence, but abruptly their implications become extremely detrimental.

Droughts have occurred in Indonesia since the 1800s (Rodysill et al., 2013), and they are linked to the country's closeness to the equator. East Java has historically undergone severe drought, which may have been caused by three massive volcanic eruptions in 1809, 1815, and 1835. Moreover, drought has historically been impacted by the cooling of SST in IPWP (D'Arrigo & Smerdon, 2008; Rodysill et al., 2013). Drought is mostly caused by the climate anomaly ENSO, which has a profound effect on Indonesia's tropical climate. Furthermore, the IOD also contributes to drought in Indonesia (Kuswanto & Naufal, 2019; Mursidi et al., 2017; Rodysill et al., 2013; Saji et al., 1999). As part of drought risk management, the modeling of rainfall and crop production is inadequate and has limited capabilities, due to the broad Indonesian archipelago's varying seasonal conditions, geography, and ENSO local climate response (D'Arrigo & Smerdon, 2008; Wilhite et al., 2000). The level of its severity is determined not only by the duration and scale of the drought but also by the detrimental effects created which is difficult to identify and quantify (Wilhite, Hayes, et al., 2000). It also exhibits vary by locale, based on the local weather and hydrological circumstances. In some provinces of Indonesia, infrequent precipitation causes drought. Eight of them, in particular, are vulnerable to drought: Riau, Jambi, South Sumatra, North Sumatra, East Kalimantan, Central Kalimantan, South Kalimantan, and West Kalimantan. Thus, the provinces most severely impacted by drought are East Nusa Tenggara, Sulawesi, and Java (Kuswanto et al., 2019; Kuswanto & Naufal, 2019; Mursidi et al., 2017). According to WFP Indonesia, East Nusa Tenggara is one of the provinces most vulnerable to drought and food insecurity, and currently is a major priority in drought handling in Indonesia.

Policy and technical methods must be employed in attempts to reduce the vulnerability of Indonesia's food security to drought. Since food and drought are inextricably intertwined, they are considered as a nexus. Recent nexus frameworks have frequently utilized three subject associations: food, energy, and water (Bijl et al., 2018; Liang et al., 2020; Sun et al., 2021). Nexus, however, is not just concerned with those three connected subjects. Other nexus subjects investigated include knowledge–innovation (Capello & Lenzi, 2014), city-level water–energy (Li et al., 2021), and environment–migration (Eklund et al., 2016). Literally, nexus means a connection of a group or system. The association will be referred to as the spatial nexus in this study, as it relies predominantly on spatial data and information. This study provides practical insight, science-based recommendations, and several strategies related to the drought–food security spatial nexus. Where it can be used as a form of risk and crisis management from various perspectives, by developing an integrated methodological framework of both proactive and reactive responses. The goal of this paper is to explain the integrated framework based on drought–food spatial nexus as our novel, which includes various related national or local government agencies, as well as their responsibilities and roles. Due to the scientific applicability of this work, the government and other parties as well as other countries, may refer to or utilize this spatial nexus framework fully or partially.

Hence, how this paper is structured into five sections. The second section presents the research overview, method and knowledge management within the nexus spatial framework. In this section also presents a discussion of how the data are collected and processed. Results and discussions will be in the third section. This section will be divided into five sub-sections including drought data handling, drought determination, utilization of drought information for food security, drought policy, and drought–food security spatial nexus. While the fourth section will provide a conclusion.

2. Methods

2.1 A comprehensive research overview

The research was conducted by applying The Republic of Indonesia as a case study given its geographical position near the equator and its tropical environment as shown in Figure 1. Indonesian region is surrounded to the south and west by the Indian Ocean, to the east by the Pacific Ocean, and the north by the South China Sea. Due to these circumstances, Indonesia is very vulnerable to both drought and excessive rainfall. Sea surface temperatures and winds have considerable spatiotemporal correlations that are influenced by precipitation and ocean dynamics. While the dipole mode of IOD contributes to around 12% of the sea surface temperature fluctuation in the Indian Ocean. If SST anomalies occur, where the IOD's SST is warmer than average and the oceans of nearby Sumatera's SST are colder, a drought could occur in Indonesia (Saji et al., 1999).

This study is a preliminary to the primary issue, namely the Droughts Model for Sustainable Food and Land Management based on the Spatial Nexus Framework. The three stages are carried out, adopted from earlier research on the logic of the study approach (Figure 2). The stages of construction, deconstruction, and reconstruction are examined using the desk research type (Nardelli, 2018). In this paper, the focus of the study is on construction, specifically the stage of establishing a solid foundation and advancing knowledge in building the primary issue in Indonesia (J. Webster & Watson, 2002). The term "construction" refers to the necessity of defining an initial framework in relation to the entire procedure. The proposed framework represents a novel approach to investigating our theoretical understanding of drought, which is developed within the context of both current and historical circumstances. At last, a spatial nexus framework is developed to establish the relationship between drought and food security. The next stage of the research includes deconstruction, during which a discernible disparity between theoretical constructs and empirical observations. The identified discrepancy will be subjected to analysis in the form of a comprehensive gap analysis, encompassing the identification of pertinent issues, establishment of data standardization protocols, and effective management of drought operations. Anticipatory determines will be taken to address the disparities that arise in the allocation and utilization of national resources and their impact on the environment. Additional gaps exist within the domains of culture, society, and the economic and business sectors. Subsequently, a policy-plan-program (3P) will be established among decision-makers operating at both the national and regional tiers. A new theoretical framework will be constructed and subsequently established as a foundational basis following the stage of reconstruction. The synchronization process occurs as a result of the synergistic integration of data, knowledge, and policies among various agencies. The ongoing enhancement of the adaptable 3P will be facilitated by coordination and collaboration efforts, leveraging emerging information technology such as big data. Furthermore, adaptive governance is implemented through empirical and experimental measures to address disasters broadly as done by the Australian government (Dietz et al., 2017; Nelson et al., 2008). Adaptive governance integrates local stakeholders, encompassing their expertise, resources, and community. Given Australia's vulnerability to drought (Hoque et al., 2021), we will carry out some comparisons involving this region.

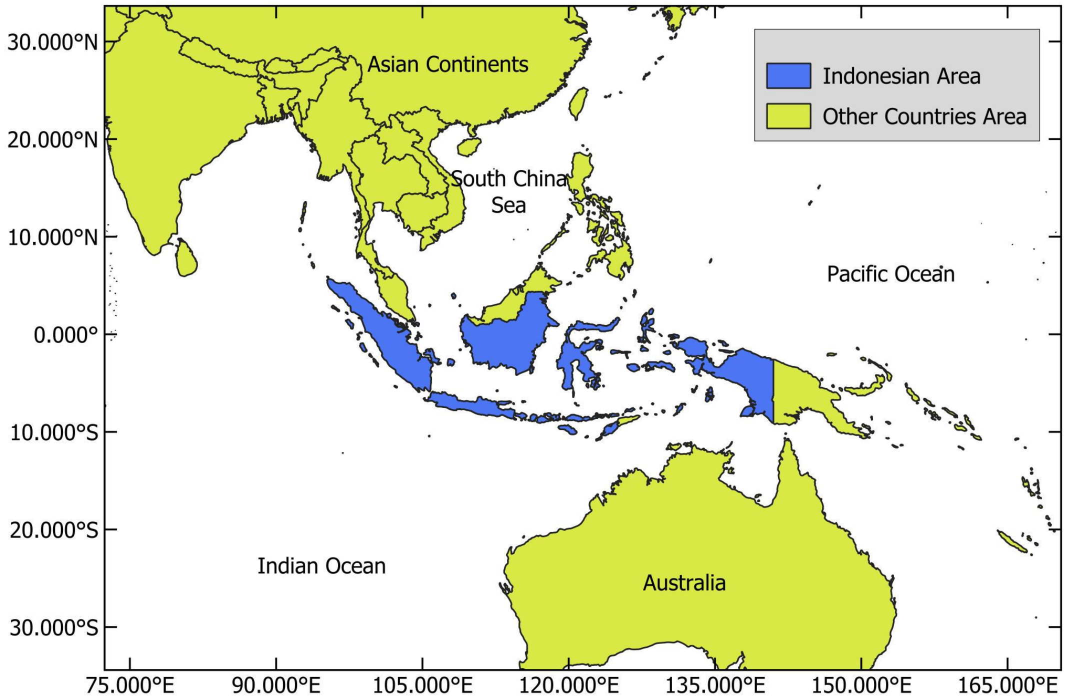

Figure 1. Map of Indonesia and the surrounding region which are downloaded from opendatasoft.com. The Indonesian area is presented in blue color. The yellow color denotes the area of other nations.

2.2 Methods

Desk research is used to resolve research issues and provide an overview of regions where the study diverges by integrating the findings and perspectives of empirical studies. It is also a great approach to synthesize study findings on a meta-level to present evidence and identify areas where more research is needed, which is an important part of developing theoretical frameworks and conceptual models. Furthermore, descriptive analysis is used to compile the state of the art in this research, which can characterize the world or a phenomenon by providing answers to questions such as who, what, where, when, and to what extent. Despite the understanding that the goals of the research are to discover and characterize trends and variations, to develop novel measurements of critical phenomena, and to identify causal effects, description is a key role in the scientific process.

Figure 2 shows the proposed framework based on the three stages adopted from other studies (Nardelli, 2018). This primary framework is a method employed from stage 1 to stage 3. Since this research is still in its first stage, the primary focus of this paper is on how to develop a state-of-the-art drought within the baseline framework, the concept of food security, and an understanding of 3P (policy-plan-program). The extensive understanding associated with drought is attributed to its complex and wide-ranging impacts. Various indicators, including duration, intensity, severity, and spatial extent, are utilized to assess and analyze drought events. However, this study will undertake a comprehensive investigation focused solely on the methods of data acquisition and processing, categorization of drought events, identification of drought occurrences, selection of suitable indicators, and the specific implications of drought on food security.

Here, we examine the current situation in relation to concepts and theories in greater depth, wherein a brief overview of the theoretical background has been provided in the introduction section. At this point, the pertinent theories involve how drought is formed, the contributing factors to drought, the impact of ENZO on the severity of drought, the methodology employed in calculating the food security index in relation to drought, the scale of regional vulnerability to food insecurity, and the requirements for sustainable food security. Several methods and techniques for identifying drought and food security will be spatially analyzed. At the end of this stage, an evaluation of its efficacy relative to the stated goals is carried out, and the spatial nexus framework and 3P concept are achieved. There is a process of synchronization between theory and practice, the involved agencies, central and regional governments, and monitoring progress through mutual coordination and cooperation. Given that our current emphasis is on the construction stage, the later stages will be subject to further investigation and analysis in future research.

2.3 Research Materials

Data and information, generally referred to as data in this paper, are obtained from the data custodians of each participant agency and are required as input for the framework, where data collection is part of the current situation analysis. There are three types of data collected based on the sources in the proposed spatial nexus framework. First, the data is gathered directly from the participating institutions, either via the web portal or a guided representative service. Currently, not all data owned by participants can be accessed via the web portal, thereby posing an obstacle to the research. An additional challenge that emerges pertains to the absence of standardized data, thereby causing the integration process more complicated. It is highly plausible that in the future, web-based data ordering could accelerate the process of obtaining data. Moving forward, it is beneficial to establish a standardized data policy that would assist in the seamless integration and processing of data.

Secondly, the data was obtained through descriptions of the participants or individuals who had personally experienced drought, as well as through tacit knowledge, and they gathered the most recent information on drought and its management in Indonesia and throughout the world. Data was gathered via a group depth discussion amongst BMKG, BNPB, MoPWH, MoRT/NRIA, MoA, and BRIN (previously, the institution was LAPAN, but through President Regulation No. 78/2021, it was merged with other research agencies as BRIN). They were instructed to review the governance and data utilization policy of any model related to drought developed by drought-related agencies in Indonesia. Each participant provides their data through a meeting presentation. The data provided includes geographical, quantitative, and narrative information. BMKG, for example, gives spatial data on monthly rainfall anomalies and monthly rainless day maps, while BRIN submits land use land cover for the last several years, medium and low spatial resolution cloud-free imagery. A conclusion was drawn up at the end of the conference, which was a compilation of all the data from the participants. Further data processing is sometimes necessary throughout the compilation process to obtain data that is spatially integrated and required by the framework. The results of the discussion were obtained in the form of current information and drought-related data of the construction stage framework.

Thirdly, the framework additionally acquired data through field surveys that were carried out in drought-affected regions, utilizing a layered purposive quota technique, questioning agricultural laborers who have engaged in farming activities for a minimum of three consecutive growing seasons. Field surveys employ techniques such as in-depth interviews and observations. In-depth interviews were performed among respondents (farmers) with a minimum of 18 years old and among village officials/extension/officials of the Local Government Organization for Agriculture who worked as agricultural extensions (per village/work area) or as village heads (per village). Observations were conducted to obtain complete data and good validity, during which the researchers collected irrigation infrastructure documentation, drought EWS, and documents related to weather information systems, planting periods, and so on. The data collected during field research was compared with the results obtained during the initial examination of desk research. Following obtaining pertinent data, a cross-validation process was conducted utilizing the technique of data triangulation, incorporating the initial dataset, updated data, and contemporaneous field conditions.

3. Results and Discussions

3.1 Data Collection Techniques, Information Processing, and Knowledge Formation of Drought

An inventory of data encompassing natural, biological, and human resources, along with the identification of constraints that may influence the framework, is consistently conducted by other country's governments. Multiple stakeholders are involved in the data and information about drought conditions (Nelson et al., 2008; Stone, 2014; Wilhite et al., 2014). Another country, Spain pooled its resources with those of its surrounding European nations to discover and develop climate models to manage droughts (Hervás-Gámez

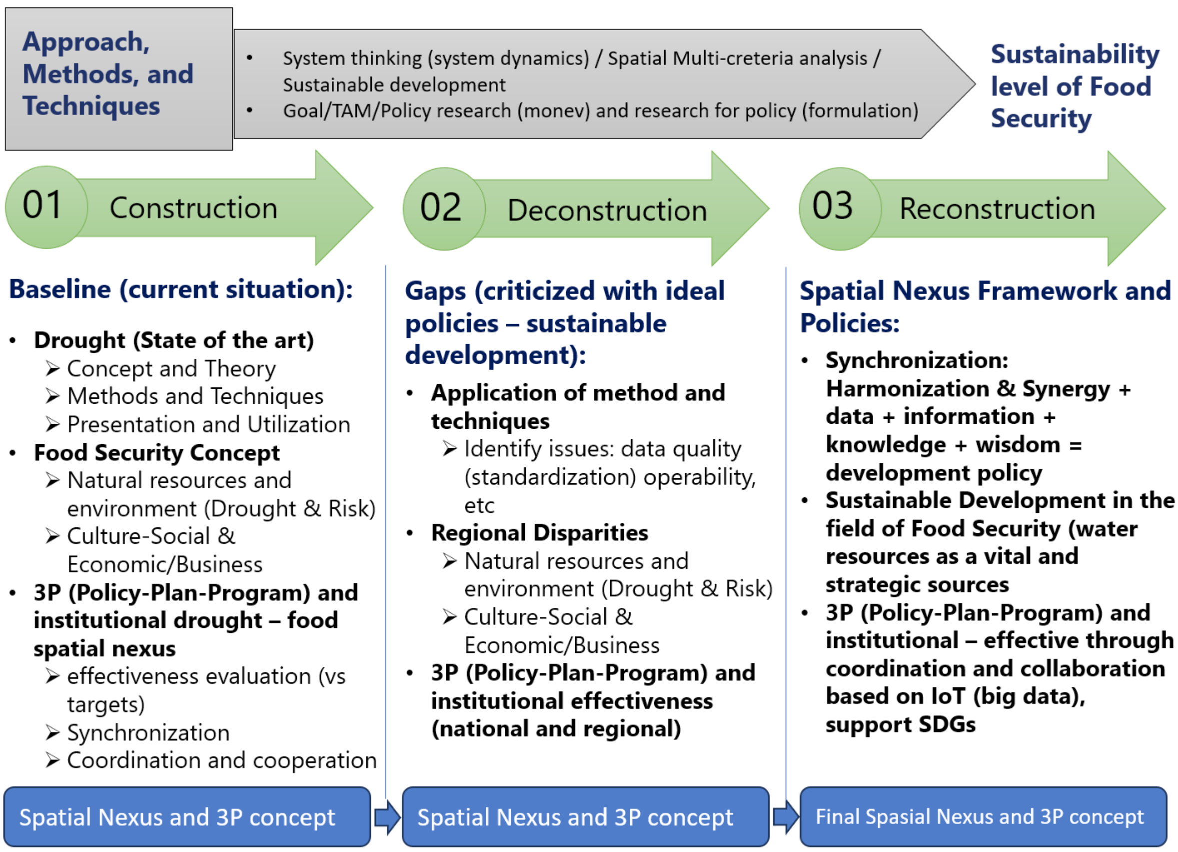

Figure 2. The primary study approaches and methods framework. The framework consists of three distinct stages, specifically construction, deconstruction, and reconstruction, which are visually represented by green boxes positioned at the technical layer level. The grey boxes describe the logic behind the various approaches, methods, and techniques employed to attain the objectives located at a higher conceptual layer. Every stage is outlined by a set of tasks and goals, which are visually represented by blue boxes at a target layer level. While the final goal, as mentioned on the upper right, is a sustainable level of food security

& Delgado-Ramos, 2019). The BMKG is a non-departmental government agency in Indonesia. Their responsibility entails the execution of government obligations related to the fields of meteorology, climatology, and geophysics as outlined in law no 31 of 2009. This includes managing regular data concerning climate, forecasting seasonal patterns and air quality, and early warning regarding severe weather conditions (King & Jaafar, 2015). The responsibilities associated with forecasting entail predicting the start and characteristics of the dry season, prognosticating and evaluating monthly precipitation trends, predicting the development of the dry season, and monitoring the frequency of rainless days to mitigate occurrences of drought. The BMKG performs analysis and forecasting of ENSO and IOD events to monitor drought intensity. Its meteorological drought early warning information is generated through the monitoring of rainless days and probabilistic rainfall forecasting. They also provide air quality information for areas prone to forest and land fires (King & Jaafar, 2015). The public can access climate information produced by the BMKG through its website (http://www.bmkg.go.id) and mobile application "InfoBMKG."

The Space Act of the Republic of Indonesia applies the Aeronautics and Space Research Organization of LAPAN (currently BRIN) role as a government agency conducting space activities including remote sensing. The mentioned act was enacted by the President of the Republic of Indonesia under the designation of Act No. 21 of the year 2013. According to the regulations outlined in Article 7 of the Space Act, remote sensing is classified as a space-based activity that encompasses a range of functions such as data collection, processing, storage, distribution, utilization, and dissemination of information. Furthermore, under regulations, BRIN is an agency that operates in the active acquisition and processing of satellite imagery for various purposes of spatial analysis including the detection of drought. The data presented in Table 1 depicts data gathered from each participant, including the name of the satellite, its technical characteristics, and its abilities pertaining to drought. The data capability of low resolution is characterized by a spatial resolution ranging from 0.5 to 5 kilometers. This type of data is commonly employed for global measurements of SST and rainfall rate. Some of those have the potential to be utilized in the calculation of vegetation indices, such as NDVI and EVI. Whereas the medium one is mostly used for the purpose of land use land covers. In the context of achieving enhanced visibility, the purpose remains mostly the same, albeit with a heightened degree of detail. On certain occasions, this data is employed for the purpose of visual verification during the execution of field checking.

BRIN also operates a Disaster Mitigation Information System (SIMBA) that offers pertinent information pertaining to the probability of flooding or drought in rice cultivation regions, a fire hazard rating system (SPBK), monitoring of hotspot conditions, volcano eruptions, fire smog, former land burned, and analysis of drought occurrences within Indonesia's territory. Furthermore, the BRIN organization comes with the Satellite-Based Disaster Early Warning System (SADEWA), which is a system designed to provide early warning information regarding severe atmospheric conditions. This system is supported by the utilization of remote sensing satellites and models that analyze atmospheric dynamics. The purpose of this application is to serve as a research and development tool that facilitates and enhances the implementation of R&D activities by other operational agencies associated with the field. The SADEWA platform can be accessed through the official website at https://sadewa.brin.go.id/.

The BBWS works as a technical implementation unit and operates within the field of water resources conservation. Its primary objectives include the development and utilization of water resources, as well as the management of water-related hazards. The BBWS falls under the jurisdiction of the Director-General of Water Resources within the Ministry of Public Works and Housing (MoPWH). In the context of drought monitoring, the BBWS organization is responsible for monitoring various water resources, including dam water availability, reservoir water availability, lake water availability,

Table 1. Satellite data gathered from the participants included information regarding the brief specifications and descriptions of the data's capabilities. The data points labeled #1 – 4, #5 – 7, and #8 – 9 correspond to spatial resolutions categorized as low, medium, and high, respectively. Group #9 consists of Synthetic Aperture Radar (SAR) data, particularly TerraSARX and Sentinel-1 data.

#	Satellites Name	Specifications	Abilities	Sources
1	Himawari-8	1 – 2 km spatial resolution, 10 minutes temporal resolution	rainfall rate, SST, cloud cover, vegetation index	BRIN, BMKG
2	TERRA/AQUA MODIS	0.5 - 1 km spatial resolution, 2 – 3 times per days acquisition	vegetation index, land use land cover, SST, drought index	BRIN, BMKG
3	Chirps 2.0	5.5 km spatial resolution	rainfall rate	BMKG
4	NOAA, Suomi - NPP	2 km spatial resolution	rainfall rate, vegetation index	BRIN
5	Landsat 5-8	15 – 30 m spatial resolution, 16 days acquisition, 8 channels	land use land cover, vegetation index, drought index	BRIN
6	SPOT 2,4,6,7	1.5 – 20 m spatial resolution, 3-4 channels	land use land cover, vegetation index, drought index	BRIN
7	ALOS	2.5 – 10 m spatial resolution	land use land cover, vegetation index, land subsidence	BRIN
8	Rapideye, Ikonos, QuickBird, WorldView	0.5 – 5 m spatial resolution, 3-4 channels	land use land cover, vegetation index	BRIN
9	TerraSarX, Sentinel-1	1 – 5 m spatial resolution	land subsidence, land deformation, soil moisture	BRIN

weir availability, groundwater sources, and the Clean Water for Rainwater Management (ABSAH) initiative. Producing data and information related to drought is not its main responsibility, but rather an additional role to support these main tasks and functions.

In addition to government agencies, non-governmental parties also play a role in the processes of data collection, information processing, and knowledge formation regarding drought. One such group is farmers, who can provide valuable information about drought events, including their location and duration. Furthermore, universities and research institutions play a crucial role in conducting research on drought. These studies generate valuable micro-scale data and information that can be utilized by relevant stakeholders.

3.2 Drought Determination

Droughts have drawn the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists, and agriculture experts as an environmental disaster. They can occur in practically all climatic zones and in high and low rainfall areas and are usually produced by a reduction in precipitation over a lengthy period of time, such as a season or a year. This study stressed the difference between a heatwave and a drought, stating that a heatwave typically lasts about a week, whereas a drought might last months or even years (F.-C. Chang & Wallace, 1987).

Droughts have an influence on both surface and groundwater resources, resulting in reduced water availability, worsened water quality, crop failure, decreased range productivity, reduced power generation, damaged riparian ecosystems, and the suspension of recreational activities. Moderate climate fluctuations modify hydrologic regimes, which have significant effects on lake chemistry (Riebsame, 2019). They can also affect a variety of economic and social activities (Riebsame, 2019; K. E. Webster et al., 1996).

Droughts are among the most slowly developing extreme meteorological occurrences, with the longest duration and, at the time, they have the least predictability of all atmospheric dangers. It is crucial to distinguish between conceptual and operational definitions when defining a drought (Wilhite & Glantz, 1987).

Operational definitions attempt to pinpoint the start, intensity, and end of drought episodes, whereas conceptual definitions are expressed in terms of relative magnitude (e.g., a drought is a lengthy, dry time). Drought frequency, intensity, and duration for a certain return period can all be calculated using operationally defined droughts (Mishra et al., 2009). Drought indicators and indices are the quantitative measures employed to depict the physical attributes of drought, encompassing factors such as the length of time, intensity, and geographical scope.

The following are some examples of regularly used drought definitions. Drought is defined as a "sustained, extended deficiency in precipitation" by the WMO (1986), and as a "naturally occurring phenomenon that exists when precipitation is significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect the environment" by the UN Convention to Combat Drought and Desertification (1994). A drought hazard is also defined by the United Nations FAO (1983) as "the percentage of years when crops fail due to a shortage of rainfall." A drought is defined as "an extended period—a season, a year, or many years—of insufficient rainfall relative to the statistical multiyear mean for a province" by the Encyclopedia of Climate and Weather (1996). This study defines it as "the smallest annual amount of daily streamflow" (Gumbel, 1963). Drought definitions, however, differ based on the variable used to characterize it.

Drought can be classified into four distinct categories, which are determined by the underlying causes as well as the specific objects and sectors impacted. These categories include meteorological, hydrological, agricultural, and socioeconomic drought (Wilhite & Glantz, 1985). A meteorological drought occurs when a region experiences a protracted shortage of precipitation. Precipitation has long been a popular metric for assessing meteorological droughts (T. J. Chang & Kleopa, 1991; Eltahir, 1992). Meteorological drought occurs when there is a prolonged period of insufficient precipitation (Wu et al., 2020), which can lead to the development of other types of droughts. Several studies investigated droughts based on monthly rainfall data, defining drought as a precipitation shortfall relative to average values (Smakhtin & Hughes, 2007). Other techniques looked at the length and severity of droughts in connection to cumulative precipitation deficiencies (T. J. Chang & Kleopa, 1991; Estrela et al., 2000).

A hydrological drought occurs when there are inadequate surface and subsurface water resources for the established water uses of a water resources management system. Most researchers (T. J. Chang & Stenson, 1990; Clausen & Pearson, 1995; Dracup et al., 1980; Frick et al., 1990; Mohan & Rangacharya, 1991; Sen, 1980; Zelenhasić & Salvai, 1987) have used streamflow data to analyze hydrologic droughts. Geology is one of the key variables driving hydrological droughts, according to regression analysis connecting droughts in streamflow to watershed features (Vogel & Kroll, 1992; Zecharias & Brutsaert, 1988).

Agricultural drought occurs when there is not enough water available to adequately support crop production or plant growth. The onset of agricultural drought typically occurs after the onset of meteorological drought, depending on the moisture level of the soil layer beforehand. Drought in agriculture usually refers to a period of diminishing soil moisture and subsequent crop failure, with no mention of surface water supplies. Soil moisture loss is influenced by a number of factors, including climatic and hydrological droughts, as well as discrepancies between potential and actual evapotranspiration. The weather, biological attributes of the plant and its stage of growth, and physical and biological properties of the soil all influence how much water plants require. Several drought indicators based on a combination of precipitation, temperature, and soil moisture have been created to study agricultural droughts.

Since droughts are tied to the failure of water resources systems to meet water needs (Wu et al., 2020), socioeconomic droughts are linked to the availability of and demand for an economic good, typically water. These four categories of drought (Figure 3) are not mutually exclusive; rather, they correspond to distinct techniques for measuring and identifying dryness (Wilhite & Glantz, 1985).

Another major type of drought is groundwater drought, which is difficult to comprehend for water resource infrastructure designers. This challenge stems from the extensive use of groundwater due to a scarcity of surface water, as well as the difficulty of comprehending complex hydrogeological processes in relation to changes in the dynamics of hydro-meteorological variables as a result of changes in land cover (Mishra & Singh, 2010). Nevertheless,

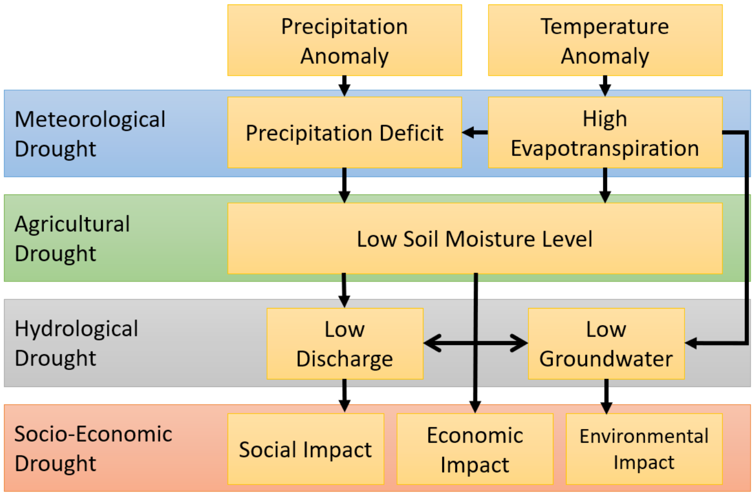

Figure 3. Different types of droughts, their interaction, and associated impacts (Van Loon, 2015)

the task of discerning various forms of drought proves to be difficult, as these occurrences can happen concurrently or consecutively and are interrelated. In actuality, drought conditions are correlated with numerous variables.

The development of drought determination is inseparable from the existence of a world-famous calculation method of drought using monthly rainfall numbers. There are at least six methods familiar to the world, namely, SPI (Siswanto et al., 2022), Decile (Abbasian et al., 2021), Standardized Precipitation-Evapotranspiration Index (SPEI) (Gumus, 2023; Zarei et al., 2023), Palmer Drought Severity Index (PDSI) (Zhou et al., 2022), and normal percentage method.

In Indonesia, the method that is often used is SPI, which is used to determine drought in an area by utilizing the calculation of deviation in the amount of monthly rainfall in a year, which is widely used also in Australia (Núñez et al., 2014). This deviation is seen from the amount of rainfall in the long term so that it can be seen the deviations experienced during a certain time. Over time, however, this SPI method has developed into the SPEI method (Siswanto et al., 2022; Vicente-Serrano et al., 2010).

According to the white paper published by the FAO in 2019, the consideration of location or area is a crucial determinant in assessing provincial drought. The quality and distribution of water resources are changing due to nature's constant search for a new balance. Thus, the quality and distribution of water resources cannot be separated from the behavior of activities of human beings, namely human anthropogenic, who continue to develop toward a place to change its geographical order. The impact of both natural and human interference on these water resources is illustrated in Figure 4, depicting the process flow in the lower left part. This is what causes drought to occur in a particular location with a unique climatic and hydrological situation. For example, in Indonesia, an average of 10% reduction in precipitations in a humid area does not necessarily result in drought, such as in the western part of the island of Java compared to the slight change in rainfall variation in the eastern part. In addition, drought is strongly influenced by local landscape characteristics that form the rain due to local hydrological cycle events. Additionally, this study examines various natural indicators and phenomena that have the potential to impact and generate water resources. Historically in Indonesia, the factors included in this set include evapotranspiration, precipitation, cloud formation, condensation, and collection.

This research examines strategies employed by Australian (Stone, 2014), Asian (Miyan, 2015), and African country's governments (Ahmadalipour & Moradkhani, 2018) to identify and analyze drought, particularly via the examination of historical drought data. The historical drought circumstances in different countries vary, resulting in varied approaches to drought management.

3.3 Utilization of Drought Information for Food Security

Agriculture experiences the most significant impact of drought in Indonesia when compared to other sectors. This phenomenon is also observed in other nations, including Australia (Stone, 2014) and USA (Stakhiv et al., 2016). The climate information produced by the BMKG can be used as input for food policy. The stages are preceded by weather forecast information that includes insights into the peak of the dry season, from which disruption to food production can be anticipated. By adding information about the potential production by the Central Statistics Agency (BPS), rising food prices and inflation can be predicted as done by another study (King & Jaafar, 2015).

The MoPWH is one of the ministries that use 10-day rainfall information generated by the BMKG for the preparation of the Annual Water Allocation Plan (RAAT) and the Annual Reservoir Operation Plan (RTOW). In addition, this information is also used by the MoPWH to construct reservoirs, irrigation canals, flood control structures, and coastal protection as well as sediment and lahar control structures.

Besides the MoPWH, the National Water Resources Council provides advice and consideration to the president in establishing and implementing national policies on water resources with stakeholders. Under Presidential Regulation No. 37 of 2018, this council relies on meteorological and climatological data generated by the BMKG and other relevant institutions.

The agricultural sector implements the Law of the Republic of Indonesia No. 19 of 2013 concerning the Protection and Empowerment of Farmers and the Regulation of the MoA No. 39 of 2018, concerning EWSs and managing the agricultural sector's climate change impact. Based on the ministerial regulation, the agricultural sector's EWS utilizes weather and climate information such as monthly rain forecasts, season forecasts, potential floods and droughts, ENSO forecasts, and potential land fires. This information is also used to mitigate the impacts of climate change and is conveyed to local governments. In addition, information regarding temperature increases, changes in rain patterns, sea-level rise, and extreme climatic events are also needed because they can affect crops. Information obtained from the BMKG and the IAARD's planting calendar database, such as information on the start of the season, rainfall, nature of rain, estimated planting time, area potential, and cropping patterns, is then compiled into an integrated planting calendar information system.

There are other agencies concerned with drought matters. BNPB is a non-departmental government agency at the ministerial level (Law No. 24 of 2007 concerning Disaster Management), comprising disaster management directors and disaster management implementers. To perform its duties and functions, BNPB relies on weather and climate information used to formulate measures related to mitigation and meteorological disaster mitigation (floods, droughts, forest and land fires, and extreme weather).

MoEF is responsible for the government's affairs in the fields of environment and forestry (Presidential Regulation no. 92 of 2020). The role of the MoEF entails the utilization of data and information on drought, which is related to climate change, forest and land fires, and watershed management. In general, MoEF utilizes data and information on air temperature and rainfall as well as elements related to air quality. Data and information related to climate elements used by the MoEF are sourced from the BMKG.

3.4 Drought Policy in Indonesia

The drought policy in this sub-section is one aspect of the 3P term, which functions as an assessment of the current policy circumstances within the framework of the drought-food security spatial nexus that is currently being constructed. At the moment, the government has encountered difficulties with establishing a comprehensive and integrated system and policy for monitoring, early warning, and dissemination of drought-related information. Such difficulties may arise from issues pertaining to the allocation of responsibilities and functions among the relevant institutions involved in managing such systems. Existing drought monitoring has been partially performed and reported by relevant government agencies such as BMKG, BRIN, and MoPWH. Meanwhile, the MoA has performed agricultural drought monitoring by utilizing data collected and processed by the three institutions. A graphical illustration of the process flow associated with the management of drought across various institutions is shown in Figure 4.

The analysis of weather indices and hydrology comes in within the authority of the BMKG and the MoPWH as illustrated in Figure 4. There is a lack of explicit regulations governing the approach of these two institutions toward addressing the issues of drought and food security. However, considerable research has been conducted in the aforementioned domain, with a particular focus on climatology and weather by BMKG, as well as watershed analysis by MPPWH.

In regards to developing a drought–food security EWS, it is important to note that relying solely on routine monitoring could be insufficient. This is due to the need for accurate prediction and anticipation of the potential impacts of drought. It is noteworthy that operational drought predictions specifically tailored for Indonesia have not been accessible up until now. The development of a drought and flood disaster prediction system for rice crops is currently underway at the Center for Research and Development of Agricultural Land Resources (BBSDLP). Nevertheless, it is imperative to acknowledge that the system is not yet ready. The implementation of an agricultural drought EWS is crucial in mitigating the detrimental effects on food production and minimizing losses.

In the context of policies, laws, and regulations in Indonesia, the issue of drought has not been deemed pertinent. The absence of any explicit mention of drought in Law Number 17 of 2019 pertaining to Water Resources is notable. It is worth noting that the subject of coercion in the provision of water resources is only briefly addressed in a specific section of Article 31. The absence of any reference to drought in Law Number 31 of 2009 is noteworthy. Instead, drought is classified as a type of natural hazard according to Article 1 of Law Number 24 of 2007, which defines it as a natural calamity. In response to the need for risk mitigation in the agricultural sector, the government has taken the initiative to designate appropriate authorities responsible for offering insurance coverage for agricultural lands. This measure aims to address the potential impact of drought and the management of irrigation in agricultural practices.

In Indonesia, the management of drought, particularly by the government, is conducted through particular organizations, specifically BMKG for the atmospheric aspect, MoPWH for the hydrological aspect, and BNPB for risks and crisis management. Additional governmental entities, such as BRIN, BIG, and BPS are also actively engaged in the management of drought by offering valuable data and information resources. Research institutions such as universities, BRIN, and non-governmental organizations were conducting analyses about the occurrence of drought and its utilization as the beneficiaries of drought data, information, and knowledge; those related to agriculture management, in particular, are MoA, MoEF, individuals, private companies, and state-owned enterprises in the agricultural sector. The distinction between the responsibilities of the institution can be illustrated as seen in Figure 4. As an exemplification, BRIN, functioning as a research institution, fulfills the role of a remote sensing data and information source, and a center for knowledge dissemination. In the meanwhile, BMKG primarily focuses on the provision of climate and meteorological data, while acknowledging some areas of overlap with BRIN.

The duties of the National Disaster Management Agency (BNPB) as outlined in Law No. 24 of 2007 encompass its role as the official representative of the government in the field of disaster management. These responsibilities encompass various aspects, including but not limited to prevention, emergency response, rehabilitation, and reconstruction. Although this law does not explicitly mention the drought disaster, the primary responsibility for addressing drought falls under the purview of BNPB. The primary objective of BNPB is to develop the crisis management of drought. Although they also play a role in the development of drought risk management as well. In the context of disaster management in Indonesia, the role of the National Disaster Management Agency (BNPB) is highly influential. Hence, with regard to regulatory frameworks and legislative measures, BNPB assumes a leading role in addressing drought conditions for both proactive and reactive responses. According to the regulation issued by the Head of BNPB in 2011, there exists a mechanism for both proactive and reactive responses. BNPB is empowered to establish standards for disaster data, including drought. One of the data arrangements observed in disaster data management is the sequential flow of activities, encompassing data collection, data processing, and data dissemination. The dataset in question encompasses pre-disaster data, emergency response data, and post-disaster data. Another regulation governing procedures to handle disasters is a regulation issued by the head of BNPB in 2018. This regulation exemplifies a reactive response by BNPB, prioritizing post-disaster mitigation efforts. The BNPB is responsible for the formulation and establishment of disaster management policies, which encompass various types of disasters, including drought. Furthermore, the BNPB serves as the coordinator of activities involving other agencies in the domain of disaster management. In the context of drought and food security, BNPB collaborates extensively with the MoA to establish robust early warning systems and preparedness measures for national drought events.

3.5 The Drought – Food Security Spatial Nexus

The descriptions of water resources obtained from the rain and the soil must be explained individually in other separate studies. Although both were inside one water system that could be recognized as the level of wetness or dryness of the area concerned, combining both precipitation and hydrological existence in one area and one time period can be referred to as the spatial nexus of natural water resources. In certain areas, this nexus symptom does not rely on technology to exchange water resources with other areas.

The spatial nexus above is a concrete manifestation of various actual entities (Whitehead, 2011), and the actual entity units that are in this spatial nexus are determined by space and time. In the context of drought, the amount of precipitation or rainfall and the volume of water discharge contained in the soil as well as on the ground surface is determined in the form of runoff, river flow, ponds or ponds, lakes, and reservoirs. The actual unity of diverse entities in this spatial nexus cannot be separated from society as its attitude and behavior toward the availability of water resources in the area is determined by formal values, which are the hallmark of society. In this research, the formal value in question is agriculture. These formal values are certainly not focused on one particular area, but they are also related to other formal values in other areas. The emerging spatial nexus in agriculture is constantly changing depending on the dynamics of the region.

The Drought Risk Management report highlights an issue pertaining to the cognitive framework of stakeholders, as pointed out by UNESCO and WWF in 2016, within the domain of drought risk reduction management. The paper explained that many weaknesses often arise. Developmental delays occur for several reasons, such as confusion about drought terminology in communication so that it often creates a mixture of understanding between hazard and impact, failure to recognize drought as one extreme event, belief in historical analogies, and failure to recognize the interrelationships between freshwater ecosystems and human welfare systems. These weaknesses, in turn, pose the following challenges: (a) the incompatibility of population growth and the availability of water resources, (b) the inconsistency between population concentration and the availability of water resources, (c) shifts in consumption patterns and economic expectations, (d) increased variability in climate and broader and more extended drought periods, (e) increased climate variability and increased drought periods, (f) increased pressures as a result of the allocation of water resources.

According to the annual final report of drought analysis for water resources management provided by the PPPSDA-MoPWH in 2014, unlike other natural disasters, droughts are slowly accumulating with unclear the beginning and the end, making it difficult to determine exactly how severe drought events are. Water resources management requires clear information on the beginning, end, and duration of droughts as well as their severity, in addition to predictions of the

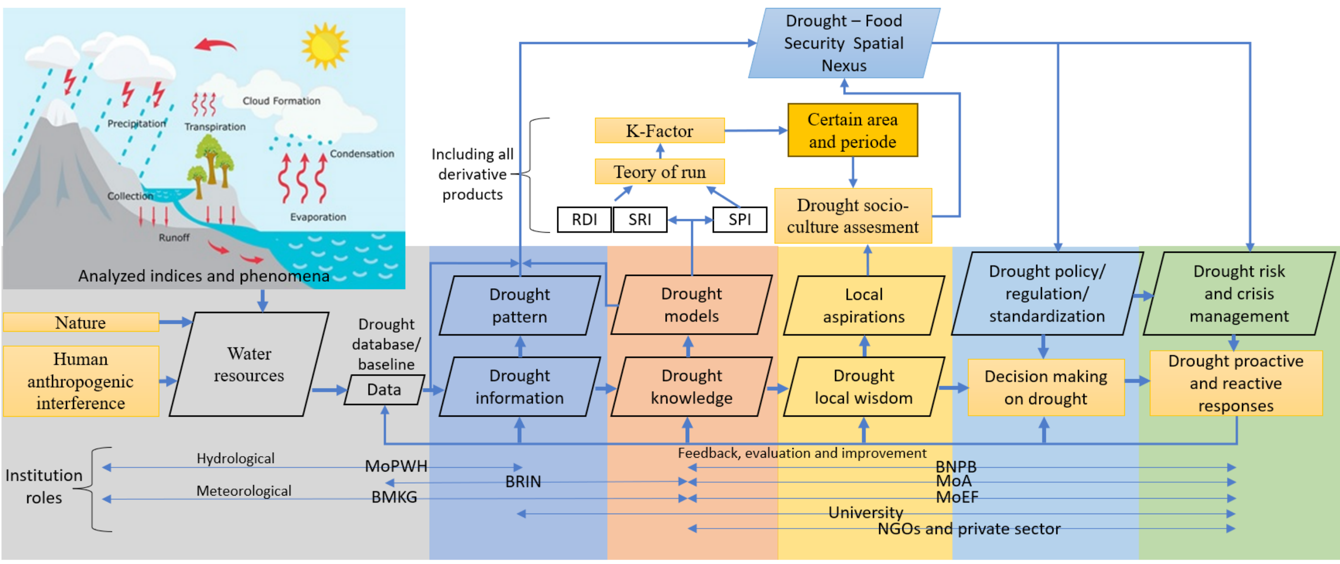

Figure 4. Process flow of the current situation of drought management process in Indonesia and its relation with the main drought–food security spatial nexus framework. Distinct variations in background colors (not a shape color) provide visual indicators of demarcations between different categories of responsibilities and tasks assigned to various agencies. K- Factor is water scarcity index method. The definition of the abbreviations are as follows. SPI: Standardized Precipitation Index; MoPWH: Ministry of Public Works and Housing; SRI: Standardized Runoff Index; MoA: Ministry of Agriculture; RDI: Reservoir Deficit Index; MoEF: Ministry of Environment and Forestry; BRIN: National Research and Innovation Agency of Indonesia; BNPB: National Disaster Management Agency; BMKG: Meteorology, Climatology, and Geophysics Agency.

occurrence of drought disasters. In the discussions related to the improvement of water resources management performance through drought analysis, various scientific indices and methodologies are employed. These include the Standardized Precipitation Index (SPI), which serves as a meteorological drought index, the Streamflow Drought Index (SRI), utilized for assessing water shortages in rivers, the Reservoir Drought Index (RDI), employed for evaluating water shortages in lakes and reservoirs, the "theory of run" for calculating water resource deficits, and the K-factor water scarcity index, which measures water shortage in irrigated areas. The correlation between these indices is visually depicted in Figure 4. These indices are integral components of the Drought Model theory. The SPI meteorological index and the hydrological drought index vary greatly from one area to another. Meanwhile, the water scarcity index uses the K-factor as an improvement on the previous water scarcity model that had involved the water resources infrastructure. The K-factor has been used since the Dutch Colonialism era (before World War II), and it is now employed, for instance, to regulate irrigation and dams based on the Regulation of the MoPWH Number: 32/PRT/M/2007. The water shortage estimate is based on human requirements and activities, such as changes to infrastructure, laws, institutions, and socio-cultural-political situations, which has an impact on extremely dynamic water supplies. The framework incorporates the drought database, pattern, model, and sociocultural assessment as supporting input parameters, illustrated in Figure 4.

Presently, the prevailing plan and program for drought management pertain to a document issued by the PPSDA-MoPWH, specifically denoted as a drought analysis report. Drought management by the Indonesian government, as stated in the drought analysis report by PPSDA-MoPWH, could be considered quite basic in principle. However, the report presents shortcomings in that it does not involve extensive groundwater resource conditions and spatial drought, which systematically affect the number of people and their activities in an area. These two elements are an important part of dealing with the problem of drought risk in agriculture and other development sectors.

An early warning system for the occurrence of drought is unavailable yet. There is a lack of comprehensive legislation and regulations in Indonesia that specifically address the issue of drought. This includes the absence of laws, ministerial regulations, and regional regulations pertaining to this matter. Currently, Indonesia has no remarkable institution or working unit that specifically handles drought; in addition, operational rules containing norms, standards, procedures, and criteria are not yet available. Hence, the issue of managing drought can be effectively addressed through the establishment of a drought–food security spatial nexus framework considerations. The spatial nexus can even be useful for dealing with the problems of forest and peatland fires, livestock and inland aquaculture, and energy from water resources as well as the need for water resources for the benefit of domestic affairs. Moreover, the issue of drought is not only related to the availability of water resources for the benefit of food in the area concerned but, in many areas, it is also related to the prevailing sociocultural and political affairs. This shows that drought significantly impacts basic human activities requiring water and food resources. In other words, the issue of the availability of water resources for the agricultural sector will increasingly become a sensitive issue in Indonesia, and the spatial nexus concept will be essential to ensure sustainable food security. The spatial nexus framework can be implemented in other countries by engaging analogous their agencies, ensuring that its application is not confined to Indonesia, contingent upon the presence of comparable agencies in those countries.

4. Conclusions

In line with climate change, drought events will tend to be more frequent and more prolonged, resulting in losses within the agricultural sector, which have an impact not only on food security but also on the domestic interests of the community. In addition, early warnings of drought events in various regions are not yet available; this is exacerbated by the lack of understanding from stakeholders, which makes it difficult to determine the beginning and end of drought events. Thus, losses due to drought become enlarged and widespread.

Systemically, drought events have involved various stakeholders, both governmental and non-governmental, and the public. Thus, a comprehensive perspective and collaboration are essential requirements for drought management, including in the agricultural sector. To be able to deal with drought, the spatial nexus of drought for agriculture can be used as a handling node as it is a comprehensive concept with multidisciplinary and interdisciplinary needs that can be implemented in other countries as well.

During the construction phase, research remains in a nascent stage as the primary emphasis is placed on conducting a thorough baseline analysis which resulting the 3P of the framework. The initial findings of this research phase can be derived from a foundational framework, which involves comprehending and analyzing the current state of conditions. These findings serve as a basis for progressing to the next stage, which entails deconstruction and reconstruction the subject matter.

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Author Contributions

All of the listed authors are main contributors, and each role is explained as follows. Triarko Nurlambang: Conception and Design, Draft Preparation, Supervision, and Writing Draft. Ratih Dewanti Dimyati: Conception and Design, Draft Preparation, Investigation, and Writing Draft. Babag Purbantoro: Conception and Design, Writing Draft, Writing Review and Editing. Nurul Sri Rahatiningtyas: Analysis, Validation and Interpretation of Data. Dewanti Aisyah Legowo: Data Acquisition, Validation, Resources, and Project Administration. Ahmad Fakhruddin: Validation, Resources, and Data Interpretation. Muhammad Dimyati: Conception and Design, Analysis and Interpretation of Data, and Supervision. Grizzly Pradipta Singhasana Enshito: Validation, Resources, and Data Acquisition.

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