Mitigating hydro-meteorological hazard impacts through improved transboundary river management in the Ciliwung River Basin

FLOOD RISK EARLY WARNING AND DECISION MAKING IN INDONESIA AND EUROPE

Update January 2022

University of HUDDERSFIELD
Inspiring global professionals

Swansea University
Prifysgol Abertawe

Natural Environment Research Council

Newton Fund

Economic and Social Research Council

This project is supported by the UK Natural Environment Research Council (Project Reference: NE/S003282/1), the Newton Fund, the UK Economic and Social Research Council, and the Ministry of Research, Technology & Higher Education of the Republic of Indonesia (RISTEK-BRIN)

About the Project

The project Mitigating Hydrometeorological Hazard Impacts Through Improved Transboundary River Management in the Ciliwung River Basin will examine how the current transboundary river management arrangements in the Ciliwung River Basin, Indonesia influence flood hazard impacts. The interdisciplinary project will bring together expertise in flood modelling, disaster risk reduction, urban planning, public policy, and behavioural science with the objective of identifying the environmental, socio-economic, political and organisational landscape associated with flood risk in the Ciliwung River Basin. The results will be used to inform improved transboundary river management arrangements for the Ciliwung Basin and provide a model for urban and peri-urban river basins elsewhere.

This project is supported by the UK Natural Environment Research Council (Project Reference: NE/S003282/1), the Newton Fund, the UK Economic and Social Research Council, and the Ministry of Research, Technology & Higher Education of the Republic of Indonesia (RISTEK-BRIN).

The Newton Fund is now a £735 million fund which, through science and innovation partnerships, promotes the economic development and social welfare of partnering countries. It aims to strengthen science and innovation capacity and unlock further funding through which the UK and partner countries will build strong, sustainable and systemic relationships. It is delivered through 7 UK delivery partners in collaboration with the partner countries. Activities are in three broad areas:

- People: increasing capacity for science and innovation in partner countries.
- Research: research collaborations on development topics.
- Translation: creating collaborative solutions to development challenges and strengthening innovation systems.

For more information visit: www.newtonfund.ac.uk and follow via Twitter: @NewtonFund

Implementing Partners

- Global Disaster Resilience Centre (GDRC) at the University of Huddersfield
- Energy and Environment Research Cluster (EERC) of the Zienkiewicz Centre for Computational Engineering (ZCCE) of the College of Engineering of Swansea University
- School of Architecture, Planning and Policy Development, Center for Coastal and Marine Development & Center for Policy Development at the Institute of Technology Bandung (ITB)
- School of Meteorology Climatology and Geophysics (STMKG)

Supporting Partners

- National Agency for Disaster Management (BNPB), Indonesia
- Indonesian Agency for Meteorological, Climatological and Geophysics (BMKG)
- National Planning and Development Agency-Directorate of Irrigation and Water Infrastructure (BAPPENAS)
- Indonesian Local Disaster Management Organisation (BPBD)
- Major River Basin Authority for Ciliwung and Cisadane Watershed (BBWS)
- BAPPENDA in West Java and DKI Jakarta Provinces

Lead Authors

Georgina Clegg, Richard Haigh, Dilanthi Amaratunga, Harkunti Rahayu

Suggested Citation

Clegg, G., Haigh, R., Amaratunga, D. and Rahayu, H. (2022) Flood risk early warning and decision making in Indonesia and Europe January 2022. A Report of the project 'Mitigating hydro meteorological hazard impacts through transboundary river management in the Ciliwung River Basin, Indonesia'.

Contents

1. Introduction 1

2. Methodology 2

3. Key concepts 3

3.1. Early warning systems - - - 3
3.2. End-to-end EWS - - - 3
3.3. People-centred EWS - - - 3
3.4. Monitoring and forecasting - - - 4
3.5. The 'human' element in early warning - - - 4
3.6. Multi-hazard EWS - - - 4
3.7. Governance and decision-making - - - 5

4. Flood early warning procedures in Indonesia 6

4.1. Risk knowledge - - - 6
4.1.1. InaSAFE (Scenario Assessment for Emergencies) . . . 6
4.1.2. InAWARE . . . 6
4.1.3. InaRISK (Hazard risk index monitoring in Indonesia) . . . 6
4.2. Monitoring and warning: National - - - 6
4.2.1. Weather forecasting . . . 6
4.2.2. MHEWS (Multi-hazard Early Warning System) . . . 7
4.3. Monitoring and warning: Local - - - 7
4.3.1. J-FEWS . . . 7
4.3.2. Integrated Jakarta FEWS . . . 7
4.3.3. Coastal Inundation Forecasting System . . . 8
4.3.4. FEWEAS . . . 8
4.3.5. FEWS in the Ciliwung Basin . . . 8
4.4. Communication and dissemination - - - 8
4.5. Preparedness and response - - - 9
4.6. Governance framework - - - 9
4.7. Multi-hazard approaches - - - 9

5. Flood Forecasting and early warning in Europe 10

5.1. Europe-wide systems - - - 10
5.1.1. EFAS . . . 10
5.1.2. Meteoalarm . . . 10
5.1.3. EU Metnet . . . 10
5.2. Flood forecasting and early warning in England and Wales - - - 11
5.3. Flood forecasting and warning in German transboundary basins - - - 12

6. Discussion 13

References 16

1. Introduction

The downstream reaches of the Ciliwung River, Java, Indonesia are frequently impacted by flooding. The river basin is also known to suffer from a series of governance challenges that prevent floods from being effectively mitigated. Such challenges include poor vertical and horizontal coordination between basin stakeholders, limited institutional capacity and a lack of stakeholder and public participation (Clegg ***et al.***, 2019). In order to address these challenges, the project ***Mitigating hydrometeorological hazard impacts through improved transboundary river management in the Ciliwung River Basin*** (CRB) aims to develop plans for more integrated flood management and river governance. As part of this, plans for improved end-to-end flood early warning arrangements will be developed, answering the question ***how can weather monitoring and forecasting for extreme events (local rain) and real time river monitoring be better integrated into a standard operating procedure to strengthen end-to-end flood risk early warning and decision making for the Ciliwung River?*** The purpose of this report is to identify the concepts relevant to end-to-end flood early warning, and to understand current approaches taken, including how they are governed. Current arrangements in Indonesia are described, along with examples from Europe for comparison. The findings are based on a review of the available literature.

This report is structured as follows: Firstly, the methodology of the review is given. This is followed by an outline of relevant key concepts. The report goes on to describe the current status of flood early warning arrangements in the CRB/Indonesia, and Europe. A discussion of the findings and questions for future research are then given.

2. Methodology

The findings of this report were identified from a systematic review of the literature guided by the following research questions:

1. What are the key concepts relevant to end-to-end flood early warning?
2. What is the current status and availability of flood early warning in Indonesia (including current approaches, and governance arrangements)?
3. How is flood early warning conducted in European countries, and what lessons can be learned?

Key search terms included: 'end-to-end early warning'; 'people-centred'; 'multi-hazard early warning'; 'flood'; 'forecasting' and/or warning and/or monitoring'; 'extreme events'.

These terms were then searched in combination with location specific searches: 'Indonesia'; 'Ciliwung'; 'Jakarta'; 'United Kingdom'; 'Europe'; 'European Union'. Where necessary, further searches for specific topics that arose during the review were conducted to gain further depth.

Searches were conducted using Google/Google Scholar and the University of Huddersfield's online library portal. The review included the following document types: Journal article, conference paper, book section, organisational reports by recognised bodies (United Nations, World Meteorological Organisation etc.). Documents were regarded to be relevant if they related to natural hazard EWS in general, or flood related systems. Documents relating to other hazards or non-relevant locations, were excluded. Documents were assessed for relevance through an initial judgement of the title, followed by an abstract scan. Only documents in English were considered.

3. Key concepts

3.1. Early warning systems

An early warning system (EWS) is defined by the United Nations Office for Disaster Risk Reduction (2020) as "An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events". EWS are a key component of successful disaster risk management. EWS can exist for a single hazard, or for multiple hazards (see Section 3.6). A flood EWS (or FEWS) is designed to address flooding specifically.

3.2. End-to-end EWS

EWS are sometimes termed 'end-to-end'. This refers to the linkages through the system from the initial monitoring of conditions to the reception of the warning by the user. End-to-end EWS are often considered to consist of four connected elements: risk knowledge, monitoring and forecasting, dissemination and communication and preparedness and response (UNDRR, 2020). The four elements are described as follows:

1. **Risk knowledge –** The collection and analysis of risk data to help authorities and the public to understand risk and to support decision making. This likely includes an understanding of where those at risk are located, as well as assessments of peoples coping capacities.

2. **Monitoring, forecasting and warning –** Monitoring and forecasting of hazard variables supports the generation of a warning in advance of a hazardous event. Such activities should be conducted continuously. Ideally this will involve coordination across different hazard activities to support the detection of multi-hazard events.

3. **Dissemination and communication –** Messages should be communicated in a way that is clear and understandable, and be deemed trustable by the receivers. The dissemination of warnings should take place through established channels in a manner that reaches all those at risk.

4. **Preparedness and response –** Preparedness enables those at risk to know how to, and to be able to, respond to a warning when required. There should be plans in place for what people should do, as well as education programmes to raise awareness.

(WMO, 2018).

3.3. People-centred EWS

EWS that are end-to-end and composed of the above four elements may also be 'people-centred'. This means that those at risk are 'central' to the system. The systems are designed to address the needs of those at risk and help to empower people to act (United Nations, 2006). UNISDR (2006) identify several important 'cross-cutting' aspects that support people-centred EWS. This includes 1. effective governance, 2. involvement of local communities, 3. consideration of gender perspectives and cultural diversity, and 4. a multi-hazard approach.

3.4. Monitoring and forecasting

Monitoring and forecasting aspects of FEWS enable the generation of a warning prior to the onset of a flood (WMO, 2018). Monitoring for river floods commonly takes the form of a gauge network, where conditions, such as rainfall, river level, and flow are measured periodically. Such networks may have varying levels of sophistication. For example, they can be automated, or manual. Remotely sensed products (e.g. from satellites) may also be used for monitoring conditions (Associated Programme on Flood Management, 2013). While monitoring river conditions may provide an advanced warning for those downstream, an additional forecasting element can help to extend the lead time. Jain ***et al.*** (2018) notes that for flooding, this will likely involve forecasting of hydrometeorological conditions that may contribute to a flood (e.g. precipitation) in addition to observations. Forecast outputs can include river level, time of peak discharge and locations that may be inundated. Again, such flood forecast models can have various forms, levels of sophistication and accuracy. Perera ***et al.*** (2020) further note that a technical authority is often responsible for conducting monitoring and forecasting activities and subsequently distributing the warning to those at risk.

While there have been large advancements in meteorological forecasting capability with Numerical Weather Prediction (NWP) (Bauer ***et al.***, 2015), and thus improved flood forecasting ability, prediction of floods driven by localised convective rainfall remains challenging. Even when conducive weather is identified via NWP, the lead time between identification and the flood occurring can be short due to their rapid onset (Flack ***et al.***, 2019). Some NWP models can now resolve local convection; however, such models are computationally intensive, costly, and thus not available to all (Zanchetta and Coulibaly, 2020).

3.5. The 'human' element in early warning

Closely linked to people-centred approaches to EWS is the concept of the 'human' element in early warning (Hamza and Mansson, 2019). This concerns the non-technical parts of the system, including risk perception, preparedness and response capability. These aspects rely on the perceptions, behaviours and actions of people and can result in the failure of a system is not correctly considered. However, Perera ***et al.*** (2019) identify that they tend not to be as well developed as technical components in both developed and developing countries. This can create issues for the end-to-end nature of the system by creating gaps and resulting in poor EWS performance.

3.6. Multi-hazard EWS

Multi-hazard EWS (MHEWS) concern more than one hazard. While EWS have traditionally addressed a single hazard, MHEWS have gained increasing attention in recent years. One of the primary targets of the Sendai Framework for Disaster Risk Reduction 2015-2030 is to '***substantially increase the availability of and access to "Multi-Hazard Early Warning Systems" and disaster risk information and assessments to the people by 2030***' (United Nations, 2015). The rationale for the use of MHEWS is that they more effectively account for hazards that occur at the same time, or where secondary hazards are triggered as a result of a first. Multi-hazard EWS can be more efficient, by using the same mechanisms for various hazards, as well as delivering more consistent messages for the receivers (UNDRR, 2020).

Several factors have been identified that contribute to effective MHEWS. Such factors relate to an effective governance system, including political recognition, resource provision, clearly defined roles and responsibilities of actors, awareness raising and training, and mechanisms for feedback and future improvement (Golnaraghi, 2012; Hemachandra ***et al.***, 2019).

3.7. Governance and decision-making

Suitable governance and decision-making procedures are essential to the effective operation of an EWS, and MHEWS in particular. There needs to be robust linkages between each aspect of the EWS to ensure integration and maintain the end-to-end nature of the system. This requires different stakeholders to work together (Basher, 2006). In transboundary river basins this is especially important, where information from one jurisdiction can be critical for effective forecasting and warning (Luther ***et al.***, 2017).

However, several governance challenges have been identified that hinder the effective operation of EWS. Such challenges include: differing views on responsibility, needs and expectations between stakeholders (Scolobig ***et al.***, 2015), a lack of political support (Basher, 2006; Hemachandra ***et al.***, 2019) and poor communication between vertical levels of governance (Dutta and Basnayake, 2018; Perera ***et al.***, 2019).

Governance issues can also challenge the use of people-centred approaches. In a review of people-centred disaster management, Scolobig ***et al.*** (2015) identify 'changing interactions among stakeholders' as one of the key challenges facing their application. In order to achieve greater people-centred-ness, the authors recommend that decision making power should be shared, with greater public involvement and that legal frameworks should be more flexible to allow this.

One common tool for setting out how EWS will be operated are Standard Operating Procedures (SOPs). They set out responsibilities and actions of the different involved agencies to guide the smooth operation of the process. In Asia, Dutta and Basnayake (2018) identify that while SOPs for EWS tend to be present, they are not always tested or updated frequently.

4. Flood early warning procedures in Indonesia

Each of the following sections discusses the main elements of an EWS (risk knowledge, monitoring and warning [including forecasting and prediction], dissemination and communication, and response capability [including preparedness] – see section 3.2), with a focus on how they are conducted, and the governance arrangements that support them. The institutional framework and multi-hazard approaches are also covered as key cross cutting issues.

4.1. Risk knowledge

There are several risk assessment tools available that support the risk knowledge element of early warning. This section briefly describes some of the platforms available nationally.

4.1.1. InaSAFE (Scenario Assessment for Emergencies)

InaSAFE is an open-source software that was developed by BNPB in collaboration with the Australian Government and the Global Facility for Disaster Reduction and Recovery (GFDRR). The software is designed to provide impact scenarios for a range of hazards for planning purposes. It has been used for disaster risk assessments and contingency planning for various provinces in Indonesia (Mujiburrahman, 2018; InaSAFE, 2021).

4.1.2. InAWARE

InAWARE is a decision support tool that provides hazard monitoring and early warning for disaster management agencies (not publicly available) at national and provincial levels. It brings together hazard information from difference sources in support of collaboration and disaster decision making (Mujiburrahman, 2018). InAWARE was developed with support from USAID/OFDA and the Pacific Disaster Centre (BPBD, 2021).

4.1.3. InaRISK (Hazard risk index monitoring in Indonesia)

InaRISK is a mobile application which is available to the public. It provides information from disaster risk assessments on areas that are disaster prone and potential losses and damages. Data are presented in map form. The application includes a flood hazard map which indicates flood hazard as an index (low-high) layered on the map (Widjaja, 2018).

4.2. Monitoring and warning: National

4.2.1. Weather forecasting

Weather forecasting in Indonesia is conducted by the national Agency for Meteorology, Climatology and Geophysics (BMKG). The Agency provide three-day forecasts which are publicly available via the agency's website and mobile application. A study by Perdinan ***et al.*** (2020) indicates that the precipitation occurrence forecast has good accuracy (75-77%), but for rainfall amount the accuracy is lower. In terms of warning, BMKG provide alerts for extreme weather events which can be accessed online (Susandi ***et al.***, 2018). The agency also supplies a flood potential map on the website. However, they do not provide watershed specific data (Perdinan ***et al.***, 2020) and the webpage is currently not in operation.

4.2.2. MHEWS (Multi-hazard Early Warning System)

MHEWS is another online platform hosted by BNPB (BNPB, 2021). The website provides access to three-day weather forecasts, InaRISK risk assessments, as well as a combined hazard prediction feature for hydrometeorological hazards (extreme weather, floods and landslides). Hazard prediction is provided by combining InaRISK maps with weather forecasts. Weather prediction comes from downscaled WRF (Weather Research and Forecasting Model) and is verified by data from BMKG. MHEWS has four warning levels ('no alert, advisory, watch and warning'). Currently, however, MHEWS is only used by BNPB for 'vigilance and preparedness', as the system is still being developed (Susandi ***et al.***, 2018; BNPB, 2021).

4.3. Monitoring and warning: Local

4.3.1. J-FEWS

Jakarta has its own flood forecasting system, known as J-FEWS (Jakarta Flood Early Warning System), that is operated by PusAir, Ministry of Public Works (van Heeringen, 2020). J-FEWS uses the Delft-FEWS system, designed by Deltares (Netherlands). Delft-FEWS is a data handling platform which integrates different types of data for the purposes of flood forecasting (van Loenen ***et al.***, 2014). J-FEWS uses meteorological and hydrological telemetry observations and radar with remotely sensed satellite data and precipitation forecasts (ECMWF, GFS) (van Heeringen, 2020), and makes use of Delft-3D and SOBEK models. The system also uses a coastal model of the South China Sea which enables storm surge forecasting. The system provides river discharge and storm surge forecasts for up to five days ahead (van Loenen ***et al.***, 2014).

J-FEWS has recently been combined with a FloodTags component. This enables reports of flooding, retrieved from the public via Twitter, to be incorporated into the system. This helps to provide real-time reports of ongoing flood events (Deltares, 2021).

The effectiveness of the J-FEWS system was called into question, however, during the severe floods of 1st January 2020. van Heeringen (2020) states that the system failed to provide a warning, with forecasted rainfall volumes only half of that actually experienced. It was found that the system had a hard-disk error which prevented it working correctly. They also suggest that the organisation of operational forecasting could be improved.

4.3.2. Integrated Jakarta FEWS

In addition to J-FEWS, an integrated FEWS for Jakarta was developed in 2008 by the Bandung Institute of Technology, Jakarta Provincial Government and the Asian Disaster Preparedness Centre (ADPC). The ***integrated*** element indicates that the initiative addressed both the technological ('structure') and human-based elements of the system ('culture'). To increase lead time, the initiative aimed to assimilate BMKG forecasts into the system, with BMKG sharing warnings of extreme weather with the Jakarta Crisis Center who was responsible for disseminating them. This was designed to enhance the lead time of the existing FEWS, which relied on the monitoring of water levels at water gates along Jakarta's rivers. In addition, the programme also aimed to enhance the 'culture' aspect of early warning with a series of community-based initiatives to raise awareness and increase preparedness, addressing gaps caused by the perceptions and attitudes of residents, socio-economic conditions, and so on (Iglesias, 2010; Rahayu and Nasu, 2010).

4.3.3. Coastal Inundation Forecasting System

A coastal inundation forecasting system has also been developed for Jakarta and Semarang under the Coastal Inundation Forecasting Demonstration Project (CIFDP). The system has been tested in a demonstration phase (2013-2018) with plans to make the system operational. There are further plans for the system to be linked with the tsunami EWS, contributing to a multi-hazard approach. The demonstration project was funded by BMKG and The Netherlands Government. Staff from BMKG have undergone training for operation of the system, and it will be part of their meteorological forecasting system (WMO, 2019; BMKG, no date).

4.3.4. FEWEAS

Two local flood monitoring and warning systems for river basins in Java have been developed, including Bengawan Solo (East Java) in 2015 and the Citarum River (east of Jakarta) in 2017. The systems were established under the FEWEAS (Flood Early Warning Early Action System) initiative by the International Federation of Red Cross Red Crescent (IFRC) in partnership with Red Cross Indonesia (PMI), Zurich, the Institute of Technology Bandung and other relevant authorities (IFRC, 2017).

The FEWEAS system is a web application that provides weather forecasts (up to ten days) and flood alerts (up to three days ahead) as well as real-time updates. State owned water companies (Perum Jasa Tirta), who operate automatic rainfall and river level gauges, provide observations, which are used alongside satellite data. FEWEAS is used by local governments and authorities in the Citarum and Bengawan Solo areas (IFRC, 2017). These systems are often judged to perform relatively well, but they are limited to these river basins only (Perdinan ***et al.***, 2020).

4.3.5. FEWS in the Ciliwung Basin

For monitoring and warning in the CRB, there are telemetry systems in place along the river which have various operators (van Loenen ***et al.***, 2014). Vitadhani ***et al.*** (2020) reports that there are 37 monitoring points along the Ciliwung between Katulampa and Jakarta. Some are automated, while 15 of these points still use manual monitoring through visual measurements and radio communication. The monitoring system is noted to be useful for detecting floods that originate upstream. However, it does not provide sufficient lead time for warning of localised flooding events. In addition, the manual system is also not well integrated with the wider J-FEWS system (van Loenen ***et al.***, 2014).

There is also evidence that residents of the CRB have their own self-supported EWS, where community members communicate with sluice gate keepers via walkie talkie and pass messages on to others (van Voorst, 2014; Padawangi and Douglass, 2015). Further details of this can be found in Clegg ***et al.*** (2020).

4.4. Communication and dissemination

At the national level, the majority of risk assessment and forecasting tools are available online or via a mobile application. This allows the public and authorities to access risk information freely. However, Sunarharum ***et al.*** (2020) indicate that a lack of knowledge and technical capacities among residents in flood prone areas may mean that they are not able to access, or effectively use, online warning information.

There are however other forms of warning communication used. Riama ***et al.*** (2021) conducted a survey in North Jakarta regarding residents' views on coastal flood warning. The survey found that 44% of respondents gained warning information from the media (newspaper, television) and online. Twenty eight percent of respondents to the survey reported that they get warnings from natural signs, while 27% relied on messages from family, neighbours and local authorities.

For communicating warnings in the CRB, BPBD Jakarta advise evacuation when the flood gauges indicate a flood is imminent. BPBD contact community leaders who then further disseminate the warnings via loudspeaker (Sunarharum ***et al.***, 2020).

4.5. Preparedness and response

FEWS development programmes, such as the integrated-FEWS for Jakarta (Rahayu and Nasu, 2010) (see Section 4.4.2), have incorporated community-based activities to enhance the human aspects of the system. For example, the initiative included training programmes with community-based organisations and representatives, and the development of risk maps and evacuation plans by community members with the guidance of a disaster management expert (Iglesias, 2010).

Despite such efforts, several issues have been identified that negatively impact preparedness and response action. At the planning level, Perera ***et al.*** (2020) notes that contingency plans are in place in Indonesia for emergency situations. However, they are not frequently tested or widely used. The authors also identify that there is insufficient coordination among the authorities responsible, which hinders response. Another challenge facing effective preparedness and response is the perceptions of flood prone residents. For example, in Jakarta, Sunarharum ***et al.*** (2020) suggest that residents often view floods as something that is common to everyday life, and that can be easily dealt with. Direct communication between responsible authorities and communities is also a potential issue affecting preparedness and response. There is no programme in place for raising awareness among the public in Indonesia (Perera ***et al.***, 2020). There is also a lack of common views between authorities and communities, and a lack of knowledge among those at risk, which may negatively impact communication, having knock-on effects for response action (Sunarharum ***et al.***, 2020).

4.6. Governance framework

The primary law for disaster management in Indonesia is the Disaster Management Law (24/2007). The Law highlights that early warning is a key activity in disaster situations (Republic of Indonesia, 2007). Early warning, as referred to in the Law, should include the following: a. Observation, b. Analysis of results from observations, c. Decision making by the authorities, d. Dissemination of warning information, and e. Community actions (Republic of Indonesia, 2007).

Government Regulation 21/2008 on disaster management expands on the Law's early warning requirements. Here, early warning is considered as an element of a 'situation with potential disaster' along with 'alertness' and 'disaster mitigation'. According to the Regulation, authorised agencies should carry out alertness activities, including the "organisation, installation and testing of early warning system". The EWS procedure is set out in the Regulation as follows: authorised agencies shall conduct observations, along with the community, these agencies then submit their analyses to BNPB/BPBD for decision making. Once a decision has been made, the warning is disseminated by government, private broadcasting and mass media. BNPB/BPBD then coordinate community action (Republic of Indonesia, 2008).

4.7. Multi-hazard approaches

In recent years the Government of Indonesia have increasingly recognised the importance of MHEWS. This is evidenced by initiative such as the MHEWS platform that provides hazard warnings for various hydrometeorological hazards (see Section 4.3.2). However, Mujiburrahman (2018) contends that EWS functions remain distributed across different authorities, which is not in support of a fully integrated approach.

5. Flood Forecasting and early warning in Europe

For comparison and greater depth of understanding of EWS processes, this section provides examples of FEWS from the European context. Europe was chosen as it is highly flood prone, has a long history of flood management, and has benefited from significant investment in FEWS over recent decades. Therefore, useful insights may be gained.

5.1. Europe-wide systems

5.1.1. EFAS

The European Flood Awareness System (EFAS) was specifically designed for flood forecasting in transboundary basins. It was aimed at addressing the problem of information sharing across borders where it is needed for forecasting (Thielen ***et al.***, 2009).

EFAS provides forecasted streamflow by cascading a meteorological ensemble forecast through a deterministic hydrological model. Warnings are issued when "(i) the probability of exceeding the 5-year return period discharge reaches critical values and (ii) results are confirmed by the two following ensemble forecasts" (Pappenberger ***et al.***, 2015). Warnings are not disseminated publicly, but to a network of 48 national hydrological and meteorological services in the EFAS network, both directly and through an online portal. These authorities then distribute the warnings to other users and the public. This is to ensure warnings are consistent with other nationally provided flood warning information (Smith ***et al.***, 2016).

5.1.2. Meteoalarm

Meteoalarm provides public access to Europe-wide meteorological hazard warnings, including an indication of precipitation events with a risk of flooding. The platform collects warnings from national meteorological services and presents them as a Europe-wide colour coded map (Alfieri ***et al.***, 2015). Meteoalarm is available online (Meteoalarm, 2021).

5.1.3. EU Metnet

EU Metnet (European Meteorological Services Network) is a collaborative group of 31 national meteorological services from across Europe. They collaborate on activities and initiatives. EU Metnet allows significant issues to be addressed through collaboration, where otherwise resource constraints may have prevented it. For example, much of Europe's weather originates in the north Atlantic and therefore, EU Metnet partners jointly implemented a monitoring system for the north Atlantic to improve their weather prediction systems. This is something that would not have been possible without this collaborative effort (EUMETNET, no date).

5.2. Flood forecasting and early warning in England and Wales

In England, the Met Office (MO) and the Environment Agency (EA) are the primary national agencies for weather forecasting and flood management respectively. Following the severe floods of 2007, a need for a more integrated approach was identified and a joint body between the EA and MO was established – the Flood Forecasting Centre (FFC) (Pilling ***et al.***, 2016). The FFC provide forecasts for fluvial, coastal, groundwater and surface water flooding types.

For fluvial flooding, the FFC use a grid-to-grid model, which provides spatially and temporally complete forecasts across England and Wales (Pilling ***et al.***, 2016). The model uses precipitation forecasts provided by the MO, and observations from the EAs network of gauges. The national forecast from the FFC is in addition to local flood forecasting models. The local models provide more accurate forecasts calibrated for specific locations. While the grid-to-grid model forecasts are not as accurate, they complement the local models by providing a national overview (Environment Agency, 2017).

In terms of warning products, the FFC produce a daily Flood Guidance Statement for registered Category 1 and 2 Responders. The Flood Guidance Statement provides a flood risk five-day look ahead. This enables emergency services to prepare resources in advance of a flood (Price ***et al.***, 2012; Environment Agency, 2017). Flood risk is communicated using a risk matrix of impact and likelihood giving a risk level from very low (green) to high (red) (Flood Forecasting Centre, 2020). A public flood forecast is also provided, which is distributed by the EA (England) / Natural Resources Wales (Flood Forecasting Centre, 2020).

For localised surface water flooding, the FFC provide a Surface Water Flood Risk Assessment (SWFRA) to local authorities, who are responsible for the management of local flooding. Ochoa-Rodriguez ***et al.*** (2018) conducted a survey of local authorities to identify their perceptions of the surface water flood guidance provided. Overall, the SWFRA was perceived to be useful for giving an overview of flood risk. However, it has a large resolution and therefore can be uncertain in the local context. The study's respondents suggested that the FFC forecast could be combined with a more localised system for areas prone to surface water flooding. However, local authorities generally do not have the technical capacities to operate such localised systems, which poses a challenge.

For flood risk knowledge, the Government provide an online tool where it is possible for the public to check long term flood risk by entering a postal code or town. The tool presents a map with areas at risk of flooding marked. This enables citizens to understand if they are living in an area prone to flooding (UK Government, 2019).

Flood warnings are disseminated to the public via TV news and weather reports, web, and through the FloodLine telephone service. Flood risk levels are provided for regions of England and Wales with a five-day outlook. Risk levels are traffic light colour coded from very low to high risk. There are then three levels of flood warnings 'flood alert', 'flood warning' and 'severe flood warning'. Each flood warning level is linked to an action 'prepare', 'act' and 'survive' respectively. Linking warnings to action is thought to improve response (UK Government, 2021).

5.3. Flood forecasting and warning in German transboundary basins

In contrast to the centralised FEWS in the UK, Germany has a decentralised system across its federal states.

The German national weather service (DWD) is responsible for issuing severe weather warnings, while the sixteen federal states (Lander) are responsible for provision of flood warnings and response actions in their jurisdiction. The Saxon Flood Centre, for example, give warnings for all major rivers in the state. They communicate flood warnings to other FRM authorities, as well as flood risk and peak flow information to the public via their website (Kuhlicke ***et al.***, 2019).

The decentralised governance arrangements mean that there are many flood warning centres, and there can be multiple centres along a single river that crosses state borders. For example, there are six forecasting centres along the Moselle River alone (Demuth and Rademacher, 2016). The large number of separate forecast operators could potentially create issues in delivering timely warnings. However, some solutions have been developed to address this. Firstly, for monitoring, there is a large monitoring network, but it has different operators, such as the state water management agency, agriculture, environment and forestry, private and so on. This could lead to issues sharing data. However, automation of the network has made data exchange between operators easier, and therefore a dense monitoring network can now be utilised (Demuth and Rademacher, 2016). Furthermore, the federal state forecasting centres have varying protocols, and data management and forecasting systems. This means that data may not be compatible and initially, there were issues sharing data. It was also difficult to establish common data standards between them. However, the centres collaboratively funded an initiative to develop conversion scripts, which has enabled greater data sharing. The forecasting centres also hold annual meetings in support of the sharing of knowledge and experiences (Demuth and Rademacher, 2016).

In addition to warnings provided by the Lander, there is also a publicly available online portal, Hochwasserzentralen, which provides the statuses of river gauges across the country (Hochwasserzentralen, 2021). The site links to the webpages of each German state and DWD where further information can be found. The site helps to provide a national overview and a basin wide view of flood events (Thieken ***et al.***, 2016). In some instances, the status of gauges in neighbouring states is also given, providing additional transboundary information (Hochwasserzentralen, 2021).

To support national level response there is a joint reporting and situation centre (GMLZ) of the federal office for civil protection and disasters (BKK). The purpose of GMLZ is to provide situation and resource management, and act as a national contact point (BKK, 2021). GMLZ acts for various disasters, not only floods, supporting a multi-hazard coordination. The establishment of GMLZ is thought to have improved collaboration and response in recent flood events (Thieken ***et al.***, 2016).

Due to Germanys location, many of its rivers cross international boundaries meaning that data from other states is required for flood early warning. In some instances, data exchange mechanisms have been established, along with collaboration on joint warning systems in some cases (Demuth and Rademacher, 2016).

6. Discussion

The aim of this systematic review was to identify the current arrangements for flood early warning in Indonesia, Jakarta and the CRB, and to compare them with examples from Europe. The review broadly described arrangements for the four elements of early warning (risk knowledge, monitoring, forecasting and warning, dissemination and communication and preparedness and response), each of which is discussed here.

Regarding risk knowledge (Section 4.1), the review found that there are several tools in place designed to help authorities and the public understand natural hazard risk. These take the form of online platforms or applications. The tools enable the assessment of different hazard types, supporting a multi-hazard approach. However, with the tools primarily accessed online, there is a potential issue that not everyone at risk may be able to access or use the tools (Section 4.4).

There is also no shortage of monitoring, forecasting and warning tools available. With various systems available at different scales. Weather forecasts and broad hazard predictions are available country-wide (Section 4.2), while there is additional forecasting for Jakarta, as well as monitoring networks in place in specific river basins (Section 4.3). The systems vary in their sophistication, from technological modelling and forecasting initiatives, to manual monitoring systems. Development of the systems would appear to have received significant investment, sometimes from international organisations and charities. Tools such as MHEWS (Section 4.2.2) also demonstrate a push towards a more multi-hazard approach. It is, however, unclear how well integrated the various systems are, or whether they work together.

Regarding communication and dissemination, it would appear that more recently developed tools use the internet as a primary means of dissemination. However, there is evidence of other warning channels (Section 4.4). This is positive, as multiple warning channels are considered beneficial for reaching all those at risk. It may be important to maintain other forms of warning communication, as vulnerable people may not have the facilities to access warnings online. The interconnectedness of the various warning and forecasting systems is important, as the multitude of systems may impact the ability to create one trusted voice when communicating warnings. Again, it is unclear how this plays out during an event from this review.

For preparedness and response there appear to be plans in place for evacuation, although it is suggested that these are not frequently used or tested (Section 4.5). The perceptions of those at risk and relationships with authorities may also present barriers to effective preparedness and response. In line with general research on EWS, it would appear that in Indonesia the human elements of the system, dissemination and communication, and preparedness and response, appear to have received less attention than the technological aspects and are therefore the potential weak points in the end-to-end system.

Overall, this review suggests that it is not a lack of EWS that is creating difficulties, as there are various systems in place. It is, on the other hand, potentially a symptom of how the systems are organised and how procedures are conducted. The systems are often operated by different organisations, using different technologies, and it is not clear how well the different systems link together. The linkages between the systems will be of importance for achieving fully integrated end-to-end, multi-hazard approaches (Basher, 2006; WMO, 2018). In addition, this review also does not indicate whether the systems available are meeting the needs of users, or whether they are delivering a sufficient quality of warning. The human aspects of the system would also appear to require further work, so that they do not present weaknesses (Section 4.5). It is also not clear how well linked the four aspects of the system are, or whether a suitable end-to-end mechanism is in place. The review indicates that further comprehensive research is needed to gain a complete picture of how flood early warning is conducted so that challenges may be addressed.

The report also presented some key examples of FEWS in Europe (Section 5). The UK and Germany present two contrasting approaches to early warning provision. The UK has a more centralised approach, while the German system is decentralised. While the needs and systems between Europe and Indonesia are different, Europe appears to have made greater efforts to integrate systems and demonstrate more joined up working. In the UK, the FFC is an example of a joint initiative (Section 5.2), while in Germany the state forecasting centres have made increasing efforts to work together (Section 5.3). There are also networks between German forecasting centres, as well as wider networks, across Europe such as EUMetNet (Section 5.1.3).

It should be noted that this report is based on a literature review of the English language literature only and as such, it may not be fully comprehensive. However, the report identifies several questions for future research related to the four elements of early warning (UNISDR, 2006; WMO, 2018). Future research on these questions will establish more precisely the nature of the issues identified in this review, and will support answering the question: ***how can weather monitoring and forecasting for extreme events (local rain) and real time river monitoring be better integrated into a standard operating procedure to strengthen end-to-end flood risk early warning and decision making for the Ciliwung River?***

Risk knowledge:

- How well integrated are the different risk assessment tools? Can they be linked more effectively?
- Are the risk knowledge products available meeting the needs of the users?
- Is available risk knowledge information being effectively utilised?

Monitoring, forecasting and warning:

- How well integrated are the various warning and forecasting systems?
- How do users perceive the different systems available? For example, do they prefer certain systems?
- How might greater networking and cooperation between different warning agencies be achieved?

Communication and dissemination:

- Are current communication channels reaching all those at risk?
- How do recipients currently perceive the warnings that are provided?

Preparedness and response:

- Are current response plans effective?
- How might preparedness and response be strengthened, including attitude changes among those at risk?

The future research questions are summarised in relation to the elements of early warning in Figure 1. The figure conveys the conceptualisation of EWS as four interrelated elements (risk knowledge, monitoring and warning, communication and dissemination and preparedness and response capability) with four cross-cutting issues (governance, multi-hazard approaches, diversity and community involvement) (originally set out by UNISDR (2006) and outlined in this report in Sections 3.2 and 3.3). It should be noted that UNISDR (2006) and WMO (2018) provide comprehensive checklists for assessment of the four elements of early warning which may be used to understand the elements more broadly. The questions highlighted in Figure 1 are identified as pertinent questions for research in the Indonesian context based on the literature review. Further discussion of each element in the Indonesian context can be found in the following sections: Risk knowledge (4.1), monitoring and warning (4.2 and 4.3), communication and dissemination (4.4) and preparedness and response (4.5). The two cross-cutting issues of governance and multi-hazard approaches are given in sections 4.6 and 4.7 respectively. Diversity and community involvement cut across Sections 4.3.2, 4.4 and 4.5 and are discussed in more depth in Clegg ***et al.*** (2020).

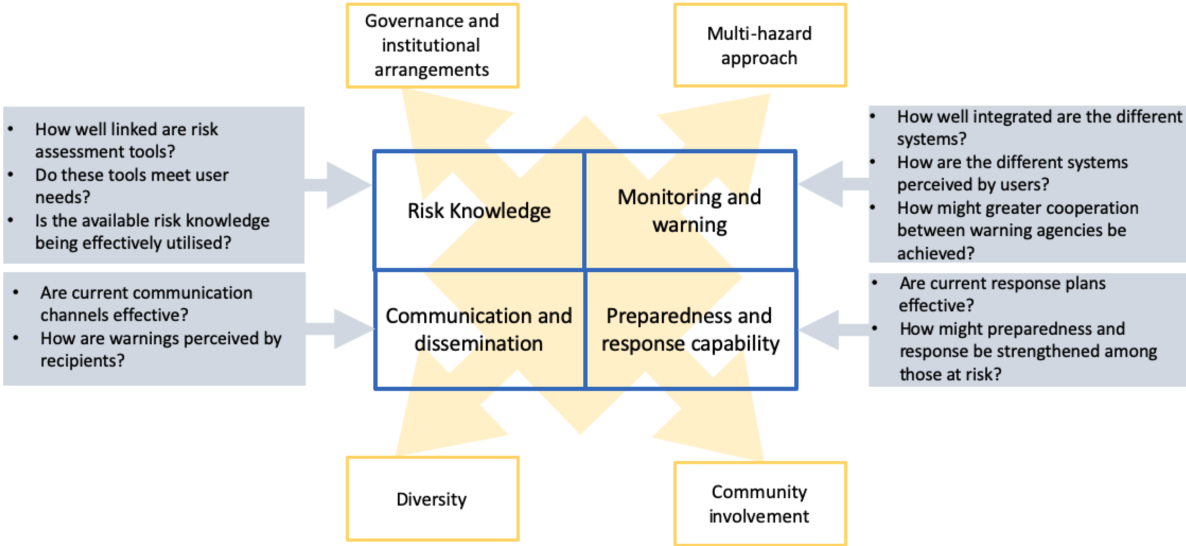

Figure 1. The four elements of early warning (blue box) with cross cutting issues (yellow) and key questions for assessment in the Indonesian context (grey). Four elements and cross-cutting issues based on UNISDR (2006);WMO (2018).

References

Alfieri, L., Burek, P., Feyen, L. & Forzieri, G. (2015) "Global warming increases the frequency of river floods in Europe". ***Hydrology and Earth System Sciences.*** 19 2247-2260.

Associated Programme on Flood Management (2013) Flood Forecasting and Early Warning. Integrated Flood Management Tools Series. Available: https://library.wmo.int/doc_num.php?explnum_id=4269.

Basher, R. (2006) "Global Early Warning Systems for Natural Hazards: Systematic and People Centred". ***Philosophical Transactions of The Royal Society A.*** 364 2167-2182.

Bauer, P., Thorpe, A. & Brunet, G. (2015) "The quiet revolution of numerical weather prediction". ***Nature.*** 525 47-55.

BKK (2021) ***Gemeinsames Melde- und Lagezentrum von Bund und Ländern (GMLZ)*** [Online]. Bundesamt fur Beevolkerungsschutz und Katastrophenhilfe. Available: https://www.bbk.bund.de/DE/AufgabenundAusstattung/Krisenmanagement/GMLZ/GMLZ_einstieg.html [Accessed 7th April 2021].

BMKG (no date) ***Coastal of Inundation Forecasting Demonstration Project (CIFDP)*** [Online]. United Nations,. Available: https://oceanconference.un.org/commitments/?id=19033 [Accessed 9th April 2021].

BNPB (2021) ***Multi-Hazard Early Warning System: Prediction of Potential Hydrometeorological Disasters in Indonesia*** [Online]. BNPB. Available: http://mhews.bnpb.go.id/#feature [Accessed 9th April 2021].

BPBD (2021) ***InAWARE Project Summary*** [Online]. BNPB. Available: https://inaware.bnpb.go.id/inaware/public/inaware_about/index.html [Accessed 9th April 2021].

Clegg, G., Haigh, R., Amaratunga, D., Karunarathna, H. U., Rahayu, H. P. & Septiadi, D. (2019) A Conceptual Framework for Flood Impact Mitigation Through Transboundary River Management. Project report.

Clegg, G., Haigh, R., Amaratunga, D. & Rahayu, H. P. (2020) A Literature Review on Community Participation in Flood Early Warning. Mitigating Hydrometeorological hazard impacts through improved transboundary river management in the Ciliwung River Basin.

Deltares (2021) ***Delft-FEWS linked to Twitter (Jakarta)*** [Online]. Deltares. Available: https://www.deltares.nl/en/projects/delft-fews-linked-twitter-jakarta/ [Accessed 8th April 2021].

Demuth, N. & Rademacher, S. (2016) Flood Forecasting in Germany - Challenges of a Federal Structure and Transboundary Cooperation ***In:*** Adams, T. E. & Pagano, T. C. (eds.) ***Flood Forecasting: A Global Perspective.*** London: Academic Press Elsevier.

Dutta, R. & Basnayake, S. (2018) "Gap Assessment Towards Strengthening Early Warning Systems". ***International Journal of Disaster Resilience in the Built Environment.*** 9 (2) pp.198-215.

Environment Agency (2017) Understanding the performance of flood forecasting models. Flood and Coastal Erosion Risk Management Research and Development Programme. Available: https://assets.publishing.service.gov.uk/media/60364fcad3bf7f0ab6856b6b/Understanding_the_performance_of_flood_forecasting_models_-_report.pdf.

EUMETNET (no date) Improving Meteorological Services Together. Available: https://www.eumetnet.eu/wp-content/uploads/2020/11/Eumetnet-Online-V2.pdf.

Flack, D. L. A., Skinner, C. J., Hawkness-Smith, L., O'Donnell, G., Thompson, R. J., Waller, J. A., Chen, A. S., Moloney, J., Largeron, C., Xia, X., Blenkinsop, S., Champion, A. J., Perks, M.T., Quinn, N. & Speight, L. J. (2019) "Recommendations for Improving Integration in National End-to-End Flood Forecasting Systems: An Oveerview of the FFIR (Flooding From Intense Rainfall) Programme". ***Water.*** 2019 (11) pp.725.

Flood Forecasting Centre (2020) Flood Guidance Statement User Guide. Available: http://www.ffc-environment-agency.metoffice.gov.uk/services/FGS_User_Guide.pdf.

Golnaraghi, M. (2012) Synthesis of Seven Good Practices in Multi-hazard Early Warning Systems. ***In:*** Golnaraghi, M. (ed.) ***Institutional Partnerships in Multi-Hazard Early Warning Systems.*** Berlin: Springer.

Hamza, M. & Mansson, P. (2019) "The human dimension of early warning - a viewpoint". ***International Journal of Disaster Resilience in the Built Environment.*** 11 (2) pp.263-274.

Hemachandra, K., Haigh, R. & Amaratunga, D. (2019) "Regional Cooperation Towards Effective Multi-Hazard Early Warning in Asia". ***International Journal on Advanced Science, Engineering and Information Technology.*** 9 (1) pp.

Hochwasserzentralen (2021) ***Hochwasser-portal: Lander-Ubergreifendes*** [Online]. Available: https://www.hochwasserzentralen.de/ [Accessed 7th April 2021].

IFRC (2017) The Flood Early Warning Early Action System (FEWEAS). Available: https://preparecenter.org/wp-content/sites/default/files/ifrc_solution_feweas_en_0.pdf.

Iglesias, G. (2010) Flood preparedness initiatives of high-risk communities of Jakarta. Safer Cities 27. Available: https://reliefweb.int/sites/reliefweb.int/files/resources/Flood%20preparedness%20initiatives%20of%20high-risk%20communities%20of%20Jakarta.pdf.

InaSAFE (2021) ***InaSAFE website*** [Online]. InaSAFE. Available: http://inasafe.org/ [Accessed 9th April 2021].

Jain, S. K., Mani, P., Jain, S. K., Prakash, P., Singh, V. P., Tullos, D., Kumar, S., Agarwal, S. P. & Dimri, A. P. (2018) "A brief review of flood forecasting techniques and their applications". ***International Journal of River Basin Management.*** https://doi.org/10.1080/15715124.2017.1411920.

Kuhlicke, C., Kunath, A., Begg, C. & Beyer, M. (2019) Resilience, the Limits of Adaptation and the Need for Transformation in the Context of Multiple Flood Events in Central Europe. ***In:*** Deeming, H., Fordham, M., Kuhlicke, C., Pedoth, L., Schneiderbauer, S. & Shreve, C. (eds.) ***Framing Community Disaster Resilience.*** Hoboken NJ: John Wiley and Sons Ltd.

Luther, J., Hainsworth, A., Tang, X., Harding, J., Torres, J. & Fanchiotti, M. (2017) World Meteorological Organization (WMO) - Concerted International Efforts for Advancing Multi-hazard Early Warning Systems. ***In:*** Sassa, K., Mikos, M. & Yin, Y. (eds.) ***Advancing Culture of Living with Landslides. WLF 2017.*** Ljubljana: Springer.

Meteoalarm (2021) ***Meteoalarm: Alerting Europe for extreme weather*** [Online]. EUMETNET. Available: https://www.meteoalarm.eu/ [Accessed 9th April 2021].

Mujiburrahman (2018) The role of universities in Indonesia multi-hazard early warning system. ***International Conference of Disaster Management 2018.*** Padang, West Sumatra, Indonesia: MATEC Web of Conferences.

Ochoa-Rodriguez, S., Wang, L. P., Thraves, L., Johnston, A. & Onof, C. (2018) "Surface water flood warnings in England: Overview, assessment and recommendations based on survey responses and workshops". ***Journal of Flood Risk Management.*** 11 (S1) pp.S211-S221.

Padawangi, R. & Douglass, M. (2015) "Water, Water Everywhere: Toward Participatory Solutions to Chronic Urban Flooding in Jakarta". ***Pacific Affairs.*** 88 (3) pp.517-550.

Pappenberger, F., Cloke, H. L., Parker, D. J., Wetterhall, F., Richardson, D. S. & Thielen, J. (2015) "The monetary benefit of early warnings in Europe". ***Environmental Science and Policy.*** 51 (August 2015) pp.278-291.

Perdinan, E.Y, A., Adi, R. F., Siregar, R., Clatworthy, Y., Nurhayati & Dewi, N. W. S. P. (2020) Meteorological Services for Forecast Based Early Actions in Indonesia. ***In:*** Leal Filho, W. & Jacob, D. (eds.) ***Handbook of Climate Services.*** Switzerland: Springer Nature.

Perera, D., Agnihotri, J., Seidou, O. & Djalante, R. (2020) "Identifying societal challenges in flood early warning systems". ***International Journal of Disaster Risk Reduction.*** 51 (101794) pp.

Perera, D., Seidou, O., Agnihotri, J., Rasmy, M., Smakhtin, V., Coulibaly, P. & Mehmood, H. (2019) Flood Early Warning Systems: A Review of Benefits, Challenges and Prospects. UNU-INWEH Report Series 08.

Pilling, C., Dodds, V., Cranston, M., Price, D., Harrison, T. & How, A. (2016) Flood Forecasting - A National Overview for Great Britain. ***In:*** Adams, T. E. & Pagano, T. C. (eds.) ***Flood Forecasting: A Global Perspective.*** London: Academic Press Elsevier.

Price, D., Hudson, K., Boyce, G., Schellekens, J., Moore, R. J., Clark, P., Harrison, T., Connolly, E. & Pilling, C. (2012) "Operational use of a grid-based model for flood forecasting". ***Proceedings of the Institution of Civil Engineers - Water Management.*** 165 (WM2) pp.65-77.

Rahayu, H. P. & Nasu, S. (2010) "Good practices of enhancement early warning system for high populated cities - a case study for Jakarta flood".

Republic of Indonesia (2007) Law of the Republic of Indonesia Number 24 of 2007 Concerning Disaster Management. Law of the Republic of Indonesia Number 24 of 2007 Concerning Disaster Management. Available: https://www.refworld.org/pdfid/5a26b1a64.pdf.

Republic of Indonesia (2008) Government Regulation of the Republic of Indonesia Number 21 of 2008 concerning Disaster Management. ***In:*** National Agency Disaster Management (Bnpb) (ed.).

Riama, N. F., Sari, R. F., Rahmayanti, H., Sulistya, W. & Nurrahmay, M. H. (2021) "The level of public acceptance to the development of a coastal flooding early warning system in Jakarta". ***Sustainability.*** 13 (2) pp.566.

Scolobig, A., Prior, T., Schroter, D., Jorin, J. & Patt, A. (2015) "Towards people-centred approaches for effective disaster risk management: Balancing rhetoric with reality". ***International Journal of Disaster Risk Reduction.*** 12 202-212.

Smith, P., Pappenberger, F., Wetterhall, F., Thielen, J., Krzeminski, B., Salamon, P., Muraro, D., Kalas, M. & Baugh, C. (2016) On the Operational Implementation of the European Flood Awareness System (EFAS). ***In:*** Adams, T. E. & Pagano, T. C. (eds.) ***Flood Forecasting: A Global Perspective.*** Academic Press.

Sunarharum, T. M., Sloan, M. & Susilawati, C. (2020) Collaborative approach for community resilience to natural disaster: Perspectives on flood risk management in Jakarta, Indonesia. ***In:*** Littlewood, J., Howlett, R. J. & Jain, L. C. (eds.) ***Sustainability in Energy and Buildings 2020.*** Singapore: Springer.

Susandi, A., Tamamadin, M., Pratama, A., Faisal, I., Wijaya, A. R., Pratama, A. F., Pandini, O. P. & Widiawan, D. A. (2018) "Development of Hydro-Meteorological Hazard Early Warning System in Indonesia". ***Journal of Engineering, Technology and Science.*** 50 (4) pp.461-478.

Thieken, A. H., Kienzler, S., Kreibich, H., Kuhlicke, C., Kunz, M., Muhr, B., Muller, M., Otto, A., Petrow, T., Pisi, S. & Schroter, K. (2016) "Review of the flood risk management system in Germany after the major flood in 2013". ***Ecology and Society.*** 21 (2) pp.51.

Thielen, J., Bartholmes, J., Ramos, M.-H. & de Roo, A. (2009) "The European Flood Alert System - Part 1: Concept and development". ***Hydrology and Earth System Sciences.*** 13 (2) pp.125-140.

UK Government (2019) ***Check the long term flood risk for an area in England*** [Online]. GOV.UK. Available: https://flood-warning-information.service.gov.uk/long-term-flood-risk [Accessed 15 April 2021].

UK Government (2021) ***Flood Warnings for England*** [Online]. GOV.UK. Available: https://flood-warning-information.service.gov.uk/warnings [Accessed 15th April 2021].

UNDRR (2020) ***Terminology: Early Warning System*** [Online]. United Nations Office for Disaster Risk Reduction. Available: https://www.undrr.org/terminology/early-warning-system [Accessed 25 March 2020].

UNISDR (2006) Developing Early Warning Systems: A Checklist. Third International Conference on Early Warning. Available: https://www.unisdr.org/files/608_10340.pdf.

United Nations (2006) Global Survey of Early Warning Systems: An assessment of capacities, gaps and opportunities towards building a comprehensive global early warning system for all natural hazards. United Nations Available: https://www.unisdr.org/2006/ppew/info-resources/ewc3/Global-Survey-of-Early-Warning-Systems.pdf.

United Nations (2015) Sendai Framework for Disaster Risk Reduction 2015-2030. United Nations Office for Disaster Risk Reduction

van Heeringen, K.-J. (2020) ***Jakarta Flood January 2020*** [Online]. Deltares. Available: https://oss.deltares.nl/web/delft-fews/-/2393390-10 [Accessed 8th April 2021].

van Loenen, A., Tollenaar, D. & Brinkman, J. J. (2014) Implementation of a Flood Management Information System for Jakarta. ***13th International Conference on Urban Drainage.*** Sarawak, Malaysia.

van Voorst, R. (2014) ***Get Ready for the Flood! Risk-handling Styles in Jakarta, Indonesia.*** PhD Thesis, Universiteit van Amsterdam.

Vitadhani, A., Alief, F., Haryanto, B., Harwahyu, R. & Fitri Sari, R. (2020) Simulating LoRaWAN for Flood Early Warning System in Ciliwung River, Bogor-Jakarta. ***2020 International Seminar on Application for Technology of Information and Communication (iSemantic).*** Semarang, Indonesia: IEEE.

Widjaja, W. (Year) Published. Loss and Damage Database and Risk Assessment and How it Contributes to Evidence-based Planning and Budgeting Processes. 2018 AMCDRR,, 2018 Ulaanbatar, Mongolia.

WMO (2018) Multi-hazard Early Warning Systems: A Checklist. Outcome of the first Multi-hazard Early Warning Conference 22-23rd May 2017 - Cancun, Mexico. World Meteorological Organization Available: https://ane4bf-datap1.s3-eu-west-1.amazonaws.com/wmocms/s3fs-public/ckeditor/files/Multi-hazard_Early_Warning_Systems_A_Checklist.pdf?fVgoQYM7LhPb3oR0V97j2.Qkjs3Wc5Rq.

WMO (2019) ***Coastal Flooding Forecast Strengthened in Indonesia*** [Online]. World Meteorological Organization. Available: https://public.wmo.int/en/media/news/coastal-flooding-forecast-strengthened-indonesia [Accessed 9th April 2021].

Zanchetta, A. D. L. & Coulibaly, P. (2020) "Recent Advances in Real-Time Pluvial Flash Flood Forecasting". ***Water.*** (12) pp.570.