# EARLY WARNING SYSTEMS IN A DIGITALISATION ERA: KEY CHARACTERISTICS AND DIRECTIONS FOR FUTURE RESEARCH

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## Abstract

*Early warning systems (EWS) can enable governments, communities and individuals to take timely action and reduce the impact of hazardous events. Modern systems for early warnings can be quintessential Government 3.0 endeavours utilising technologies towards deliver warnings that are as reliable and timely as possible through civic and enterprise collaboration locally and internationally. This paper reviews prior literature on early warning systems for Flood, Landslide and Earthquake Management. The key characteristics identified are: a) on the technical side the blending of "traditional" information and communication technologies with disruptive technologies such as data analytics, b)"soft" prerequisites for the sociotechnical arrangements including local knowledge, established standards and defined strategies and c) a set of systemic properties of critical importance related to usability, data handling velocity and integration/interoperability. These findings are consolidated in an overall framework. The systematic analysis of prior research output reveals gaps and areas for further investigation related to local knowledge, usability and the role of consumer device sensors.*

*Keywords: Early Warning Systems, sociotechnical systems, literature review*

# 1 Introduction

Early Warning Systems (EWS) are instrumental for natural disaster management. They support hazard monitoring, forecasting and prediction, risk assessment, communication and preparedness activities that enable governments, communities and individuals to take timely action to reduce the impact of hazardous events (UNISDR, 2009). Providing warnings in advance increases the timeframe for action to reduce loss of life and economic damage, furthermore, EWS seek to reduce communication gaps in emergency situations (Alfieri et al., 2012, Stankiewicz et al., 2015). Such systems are foreseen by the International Strategy for Disaster Reduction of the United Nations and the EU Civil Protection Mechanism (for EU countries and Iceland, Montenegro, Norway, Serbia, FYROM and Turkey).

EWSs are sociotechnical arrangements that leverage organizational, computational and communication capabilities bringing together actors from different governmental, non-governmental entities (e.g. technical agencies) and local communities. Issuing actionable warnings relies both on being able to detect hazards and on being able to associate with the capabilities, knowledge, and plans that are in place. Our digitalized world offers great opportunities to accumulate, process and disseminate risk-related information and to bring together different communities with different capabilities and assets. To be effective, early warning systems need not only a sound technical basis but also a strong focus on the people involved or exposed to natural hazards (Basher, 2006).

The potential of leveraging "traditional" information and communication technologies by blending them with disruptive technologies including advanced modelling, data analytics (for big datasets accumulated by sensors) and societal simulation is opening new horizons for effective EWSs. Nevertheless, as for all sociotechnical arrangements, sketching and developing configurations *that might work* is only a first step for moving to configurations *that work* (Rip and Kemp, 1998). This move requires being adapted to the context and being able to mobilize and combine requisite public sector resources (infrastructures, data, skills and knowledge) and resources beyond the public sector through public value co-creation processes engaging with a wide range of contributors.

The introduction of EWSs in current settings is a quintessential Government 3.0 endeavour. Government 3.0 refers to the utilization of technologies (within information, communication and neighbouring scientific domains), towards solving societal problems, optimising resources and improving citizen well-being, through civic and enterprise collaboration locally and internationally (Charalabidis, 2015). For instance, disaster management in South Korea is explicetly directed towards a Government 3.0 vision and systems are designed and developed accordingly (Park et al., 2015). Overall, the demand for EWS in areas prone to natural disasters has increased over the past years (Wafi et al., 2015). Nevertheless, the implementation of EWS is far from straightforward.

The impetus for our study comes from the involvement of the two first authors in a project that explores the use of early warning systems by three local communities in high-risk rural areas. This is a collaborative project between two Universities and the aim is to contribute new perspectives related to both organizational and technological aspects. The project includes extensive field work within the local communities. To inform our work for the project we identified, analysed, and integrated a critical mass of prior research on EWS. To ensure a robust and transferable result, we performed a systematic literature review guided by the following question: "What are the key characteristics of Early Warning Systems for Flood, Landslide and Earthquake Management?" Our contribution is threefold. First, we identify important aspects of EWS that need to be taken into account for introducing such systems. Second, we consolidate the findings into an overall framework. Third, we identify gaps in literature and areas for further research, and we argue that we need more research on issues related to local knowledge, usability and consumer device sensors linked to EWS infrastructures.

The remainder of the paper is organized as follows. Section 2 presents the method used for selecting and analysing the articles for this review. In Section 3, we offer an overview of our findings structured in a concept matrix and in Section 4 we synthesise them in a literature derived framework. Finally, in Section 5 we discuss the findings and conclude by identifying directions for further research.

## 2 Method

For the identification and analysis of literature for our review, we followed Webster and Watson (2002). We used specific keywords for identifying articles and a set of inclusion / exclusion criteria to ensure the quality and relevance of selected papers. Specifically, we included only peer-reviewed articles written in English, and we excluded papers that only casually mentioned Early Warning Systems but had a different focus (e.g. disaster management in general). Furthermore, we excluded papers that addressed natural disasters that were not relevant to Flood, Landslide or Earthquake Management. For instance, we excluded papers on Tsunamis, Droughts, Cyclones and Hurricanes. Additionally, both backward and forward searches were performed to enrich the selection of articles.

The term "Early Warning System" was used as a primary search term. Since Early Warning Systems are used also in contexts outside disaster management (e.g. in healthcare) we combined the term with "Disaster Management". The search was performed in Scopus. The literature search started with the main keywords: "Early Warning System" AND "Disaster Management" and yielded 253 articles.

The next step was to read the titles and abstracts of all identified articles checking their relevance to the research question. For this step we used the inclusion – exclusion criteria defined. Two of the authors went through all the articles and independently assessed them. After this step, 71 papers were shortlisted. Finally, the same two authors went through the full text of the shortlisted papers to verify that the research reported is indeed relevant to the research question for the literature review and to assess the article quality. For the quality assessment each article´s method description including data collection was checked for scientific rigorousness. After this step we ended up with only 9 articles.

To expand the set of articles to be reviewed, we repeated the process by using the search strings: "Flood Early Warning" AND "Flood Management" which yielded 2 additional articles (selected after reading through 18 shortlisted ones), "Landslide Early Warning" AND "Landslide Management" which yielded no additional article (although 6 were shortlisted and read through), and "Early Warning System" AND "Risk Mitigation" which yielded one additional article (selected after reading through 8 shortlisted articles). We also searched with the string "Earthquake Early Warning" AND "Earthquake Management" but got no new results. After this process, the number of articles increased to 12. Figure 1 presents the steps followed to identify and select the initial corpus of 12 articles.

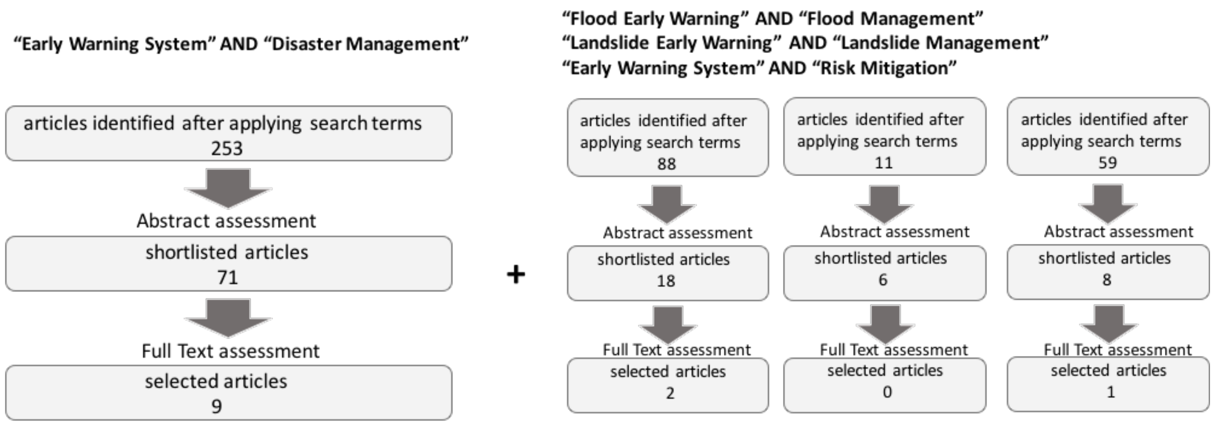


*Figure 1. Steps followed to identify and select the initial corpus of articles.*

To further expand the selection of articles, we performed a backward search. This was performed in Scopus, looking at the reference lists. Through Scopus we were able to retrieve and assess both the abstracts and the full text of cited articles. A forward search was then conducted. Overall, we identified 5 additional articles through backward searches and 3 additional articles through forwards searches ending up with 20 articles in total. The final list of articles selected is included in the Annex.

# 3 Findings

We analysed the articles selected and consolidated our findings in a concept matrix (Webster and Watson, 2002), which is presented in Table 1.

| | Technical Prerequisites | | | ”Soft” Prerequisites | | | Systemic Qualities | | |
|---|---|---|---|---|---|---|---|---|---|
| **Article No.** | **Sensors** | **Mobile-Radio-Network Communication** | **Data Analytics** | **Local Knowledge** | **Established Standards** | **Strategy** | **Usability** | **Velocity of data collection and processing** | **Integration/Interoperability** |
| 1. | X | X | X | | | | | **X** | |
| 2. | | | X | | | | **X** | **X** | **X** |
| 3. | | X | X | | X | | | | **X** |
| 4. | X | | X | X | X | | | **X** | |
| 5. | | | | X | X | X | | | |
| 6. | | X | | X | X | X | | | |
| 7. | | X | | X | X | | | **X** | |
| 8. | | | | X | | X | | | |
| 9. | | X | X | X | | | **X** | **X** | **X** |
| 10. | | | X | X | | | | **X** | |
| 11. | | X | X | | X | | | **X** | **X** |
| 12. | | X | | | X | X | | **X** | |
| 13. | X | X | X | X | X | | | **X** | |
| 14. | X | X | X | X | | | | **X** | **X** |
| 15. | | X | | X | X | X | | **X** | |
| 16. | | X | X | | | | | **X** | **X** |
| 17. | | X | | X | X | | | **X** | **X** |
| 18. | X | | X | | | | **X** | **X** | **X** |
| 19. | X | X | X | | | | | | |
| 20. | | X | X | | | | | **X** | **X** |

*Table 1. Concept Matrix derived from the articles reviewed*

Several articles foreground the technical capabilities of systems including data analytics, sensors, mobile-radio-network facilities for communication. Data analytics are required for analysing all types of data, as for instance, the rich datasets generated by satellites (Billa et al., 2004, Sali et al., 2015, Yang et al., 2015, Yusoff et al., 2015a, Afzaal and Zafar, 2017). Different communication technologies are used for disseminating early warnings, the use of both TV/radio and mobile phone technology is common (Osanai et al., 2010, Fathani et al., 2016) although in several cases only mobile phones are used (Limlahapun et al., 2011, Yusoff et al., 2015a, Smith et al., 2017). Furthermore, the advent of cloud technologies is opening up new opportunities (Yusoff et al., 2015b). Networks and sensors are frequently discussed together in the literature (Limlahapun et al., 2011, Rahman et al., 2016, Afzaal and Zafar, 2017) since it is important to be able to both register and transmit information. Sensors of secondary signals can be used for early detection of hazardous events. For instance, early warnings for earthquakes can be issued by detecting unstable animal behaviour, variations in water level and radon gas emission (Rahman et al., 2016, Afzaal and Zafar, 2017).

Furthermore, prior research also indicates the significance of non-technical aspects of the systems pointing to the importance of local knowledge, established standards and defined disaster management strategies. These are “soft” prerequisites for a successful EWS. For instance, having in place and using established standards is critical for the success of EWS (Cao and Zhou, 2008, Picozzi et al., 2013, Chen and Wu, 2014, Fathani et al., 2016, Smith et al., 2017).

Taking a holistic systemic perspective, crucial characteristics for the whole early warning system are the possibility to integrate and ensure interoperability with other existing systems, the velocity of data handling and usability. For instance, earthquake monitoring by satellites relies on processing real-time information (Nakamura et al., 2011, Sali et al., 2015). For discretionary use of EWSs, usability is believed to be critical (Limlahapun et al., 2011), furthermore, integrating different subsystems is important for improving efficiency (Sali et al., 2015).

As illustrated in table 2, the articles reviewed cover all three types of hazards (Floods, Landslides and Earthquakes). Interestingly, the key technical and “soft” prerequisites identified are common for all types of hazards. Similarly, at the systemic level, integration and real-time information processing span all types of hazards.

| **Article No.** | **Earthquakes** | **Floods** | **Landslides** |
|---|---|---|---|
| 1. | X | | |
| 2. | | X | |
| 3. | X | | |
| 4. | X | | X |
| 5. | | X | X |
| 6. | | X | |
| 7. | | | X |
| 8. | | | X |
| 9. | | X | |
| 10. | X | | |
| 11. | | | X |
| 12. | X | | |
| 13. | X | | |
| 14. | X | | |
| 15. | | X | |
| 16. | X | | |
| 17. | | X | |
| 18. | | X | |
| 19. | | X | |
| 20. | | X | |

*Table 2. Types of hazards covered in the articles reviewed*

EWSs contribute to better coordination, increased trust and better informed decision-making for risk assessment. Coordination between national government, local government, organizations and individuals is discussed in several articles (Chen and Huang, 2010, Chen and Wu, 2014, Fakhruddin et al., 2015, Fathani et al., 2016). By focusing on coordination also trust can be improved, improving the situation for all parties (Chen and Huang, 2010, Jaiswal and van Westen, 2013). Trust has been discussed as an essential factor for successful EWS by Jaiswal and van Westen (2013), Fathani and colleagues (2016) and Smith and colleagues (2017). With coordination between local government and authorities, damages can be reduced (Smith et al., 2017). To better inform decision-making the procedures of EWS are continually upgraded and expanded (Chen and Huang, 2010, Chen and Wu, 2014) while risk assessment is crucial (Fakhruddin et al., 2015, Fathani et al., 2016).

# 4 Synthesis of EWS key characteristics

This literature review on the key characteristics of Early Warning Systems for Flood, Landslide and Earthquake Management identified that on the technical side, both traditional technologies (for instance, for radio transmission) and novel disruptive ones (such as data analytics) have central roles. Interestingly, these general types of technologies are key for all types of hazards studied (floods, landslides, earthquakes). Furthermore, "soft" prerequisites (that can be constraining or facilitating the introduction and use of EWSs) were also identified including local knowledge, established standards and defined strategies. Finally, a set of systemic, sociotechnical properties of critical importance were also identified (related to usability, velocity, integration/interoperability).

We synthesised all aspects found in the literature in an overarching framework presented in figure 2.

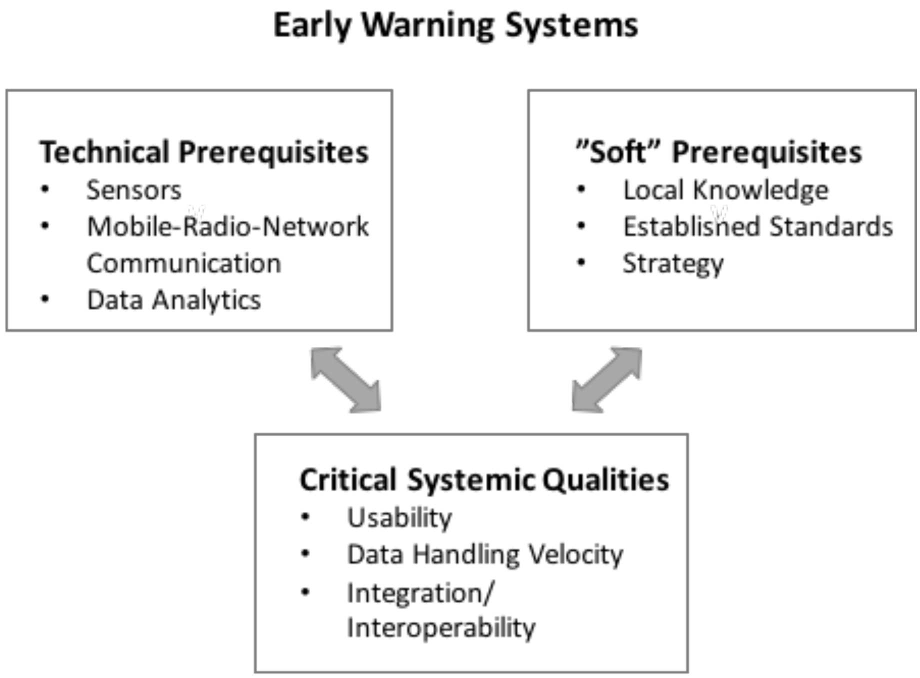


*Figure 2. Key characteristics of Early Warning Systems: an overarching framework.*

# 5 Discussion and Conclusion

Early warning systems can enable governments, communities and individuals to take timely action and reduce the impact of hazardous events. Modern systems for early warnings are blending "traditional" information and communication technologies with disruptive technologies to deliver services that are as reliable and timely as possible. Nevertheless, issuing actionable warnings relies both on being able to detect and transmit information on hazards and on being able to associate with the capabilities, knowledge, and plans that are in place. EWSs are complex sociotechnical arrangements that need not only a sound technical basis but also a strong focus on the people involved or exposed to natural hazards (Basher, 2006).

Although EWS require a strong people focus, EWS usability remains relatively underexplored. The importance of usability is identified but more work is needed towards the development of concrete design principles for the special use settings of EWSs (stressful conditions influence the perceptual and cognitive abilities of users). Furthermore, usability needs to be explored for different communication modes addressing different user groups and contexts. Additionally, the relationship between usability and trust building to governmental authorities needs to be investigated.

Several of the articles reviewed address the issue of inadequate local knowledge to handle disaster situations. Some of them present possible solutions to expand local knowledge by sharing experiences and results and dedicated programs are frequently used. Increased local knowledge and understanding can also enhance the trust between local communities and national authorities in situations of natural disasters. In addition, it is important to ensure the involvement of women especially in developing countries. In particular, competence building regarding the use of EWSs, and making such systems available to the female population, are essential for ensuring that critical information is communicated effectively in emergency situations.

Regarding technical prerequisites, one significant area for further research relates to the role of sensors in the further evolution of EWSs. There is great potential to link consumer devices to government infrastructure expanding the networks of sensors available. Such an expansion requires that governmental authorities will trust citizens and their devices as information providers. This is an interesting twist. Up to today, a key challenge for Early Warning Systems was to build the trust of citizens to governmental authorities distributing warnings. For the advent of Government 3.0, governmental authorities need to build trust towards the citizens for expanding critical infrastructures by making the most of their capacities in alignment with societal needs.

## Annex: List of Articles Reviewed

| No. | Authors | Articles | Year | Outlet |
|---|---|---|---|---|
| 1. | Afzaal & Zafar | Towards Formalism of Earthquake Detection and Disaster Reduction using WSANs | 2016 | International Conference on Frontiers of Information Technology |
| 2. | Billa, Mansor & Mahmud | Spatial Information Technology in Flood Early Warning Systems: An Overview of Theory, Application and Latest Developments in Malaysia | 2004 | Disaster Prevention and Management |
| 3. | Cao & Zhou | Research on Emergency Response Mechanisms for Meteorological Disasters | 2008 | ISECS International Colloquium on Computing, Communication, Control and Management |
| 4. | Chen & Huang | Non-Structural Mitigation Programs for Sediment-Related Disasters after the Chichi Earthquake in Taiwan | 2010 | Science Press and Institute of Mountain Hazards and Environment |
| 5. | Chen & Wu | Debris Flow Disaster Prevention and Mitigation of Non-Structural Strategies in Taiwan | 2014 | Science Press and Institute of Mountain Hazards and Environment |
| 6. | Fakhruddin, Kawasaki & Babel | Community Response to Flood Early Warning System: Case Study in Kaijuri Union, Bangladesh | 2015 | International Journal of Disaster Risk Reduction |
| 7. | Fathani, Karnawati & Wilopo | An Integrated Methodology to Develop a Standards for Landslide Early Warning Systems | 2016 | Natural Hazards and Earth System Sciences |
| 8. | Jaiswal & Westen | Use of Quantitative Landslide Hazard and Risk Information for Local Disaster Risk Reduction Along a Transportation Corridor: A Case Study from Nilgiri District India | 2012 | Natural Hazards |
| 9. | Limlahapun, Fukui, Yan & Ichinose | Integration of Flood Forecasting Model with the Web-Based System for Improving Flood Monitoring, and the Alert System | 2011 | International Conference, Automation and Systems |
| 10. | Nakamura, Saita & Sato | On an earthquake early warning system (EEW) and its applications | 2011 | Soil Dynamics and Earthquake Engineering |
| 11. | Osanai, Shimizu, Kuramoto, Kojima & Noro | Japanese early-warning for debris flows and slope failures using rainfall indices with Radial Basis Function Network | 2010 | Journal of the International Consortium on Landslides |
| 12. | Picozzi, Bindi, Pittore, Kieling & Parolai | Real-Time Risk Assessment in Seismic Early Warning and Rapid Response: A Feasibility Study in Bishkek (Kyrgyzstan) | 2013 | Journal of Seismology |
| 13. | Rahman, Mansoor, Deep & Aashkaar | Implementation of ICT and Wireless Sensor Networks for Earthquake Alert and Disaster Management in Earthquake Prone Areas | 2016 | Procedia Computer Science |
| 14. | Sali, Zainal, Ahmad, Omar & Mohammad | Remote earthquake monitoring over GEO satellite network | 2015 | Conference: RAST 2015 |
| 15. | Smith, Brown & Dugar | Community-based early warning systems for flood risk mitigation in Nepal | 2017 | Natural Hazards and Earth System Sciences |
| 16. | Stankiewicz, Bindi, Oth & Parolai | Toward a cross-border early-warning system for Central Asia | 2015 | Annals of Geophysics. |
| 17. | Wafi, Abdmalek, Alnajjar & Ahmad | Early warning system for Disaster management in rural area | 2015 | ISTMET 2015 |
| 18. | Yang, Chen & Sun | A big-data-based Urban flood defense decision support system | 2015 | International Journal of Smart Home |
| 19. | Yusoff, Din, Yussof & Khan | Big data analytics for Flood Information Management in Kelantan, Malaysia | 2015 | IEEE Student Conference on Research and Development |
| 20. | Yusoff, Mustafa, Yussof & Din | Green cloud platform for flood early detection warning system in smart city | 2015 | NSITNSW 2015 |

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