Chapter 7
The Necessity of Early Warning Articulated Systems (EWASs): Critical Issues Beyond Response

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1 Introduction

Disaster risk reduction (DRR) and disaster risk management (DRM) are without a doubt goals that all governments urgently need to move towards. Disasters associated with tsunamis triggered by earthquakes, such as those of the Indian Ocean (2004), and on the Pacific coast of Tōhoku (2011), Japan, have represented the two sides of the same coin. On the one hand, the need for developing tsunami warning systems has indeed been a priority for the Southeastern region of Asia, but on the other hand, the evaluation of warning systems protocols for multi-risk scenarios became an urgent issue for Japanese society. Lessons from both cases clearly provided an urgent and challenging mission for the rest of the world.

Despite scientific and technological advances, current early warning systems (EWSs) cannot yet be seen as a promising answer for disaster prevention. First of all, there is a lack of effective and efficient EWSs given that risk, as a socially constructed process, possesses various spatial and temporal scales and dimensions. Secondly, in addition to individual hazard occurrences, multi-hazard forecasting has not yet been perceived as a widespread condition and therefore scenarios of hazard concatenation are usually neglected as a paradigm of integrated disaster risk research is not yet common. Thirdly, and perhaps most importantly, in addition to scientific uncertainty, social factors are indeed the greatest restraint above all.

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Decision-making processes are multi-factorial dependent, and particularly in developing countries, actions are taken as a function of political momentum and individual interest. As such, lessening disaster effects has not yet been made a priority practice. As a result of the missing communication links among authorities, scientists, decision makers and populations, including their traditional knowledge, and all other involved actors in disaster risk, specifically in societies or communities characterized by high levels of vulnerability and low resilience, EWSs cannot be seen as articulated systems, but as segments of the capacity-building process needed to achieve DRR and DRM.

EWSs will fall short in true effectiveness in reducing disaster risk and impact if the science and technology do not take into account the social factors involved in decision-making processes at all levels of society. This chapter proposes that EWSs therefore must be articulated in tandem with institutions, authorities, science, decision makers and all other communities involved in DRR. EWASs can, in this sense, be defined as a coordinated structure for the implementation of specific strategies of action to achieve DRR and DRM based on the understanding of disaster risk as a socially constructed process. Disaster risk is not only influenced by the occurrence of hazards, but also possesses various spatial and temporal scales and dimensions of vulnerability that are shaped by risk drivers and causes rooted in historical processes. As such, EWASs need to consider both the single and the concatenated effects of hazards on exposed communities, capital and environmental assets.

This chapter aims to shed light on the identification of critical issues that need to be taken into account to develop and implement EWASs within a framework that goes beyond response and is based on integrated science for disaster risk and the notion of long-term communication. It is divided into five parts. An introduction to understanding disasters is given in the first section, which involves the paradigm of "unnaturalness" that seeks to demonstrate the social construction of risk and emphasize the significance of small- and medium-size disasters in building the multiple dimensions of exposure and vulnerability. Failure to recognize these factors constitutes an obstacle to achieving resilience, development, sustainability and disaster risk reduction and management.

Section 2 focuses on the general impact of disasters worldwide and the role that large-scale disasters have played in inspiring the implementation of EWSs. Particular attention is given to the Indian Ocean Tsunami (2004), Hurricane Katrina (2005) and the Tōhoku Earthquake (2011). The need for an integrated approach for the construction and implementation of sound EWASs is addressed in Sect. 3, where particular attention is given to the concepts of uncertainty, integrated science, risk communication and governance. In the final section, some concluding remarks are offered.

2 Disasters: A Prelude

2.1 The "Unnaturalness" of Disasters: A Quick Look into Socially Constructed Processes

Disasters associated with natural and anthropogenic hazards, climate change and morphological changes of the Earth's surface induced by both natural and human-influenced processes are indeed one of the greatest challenges for science, technology and development in the twenty-first century. As populations grow and vulnerability increases at local, regional and global scales, the human, environmental and economic consequences of disaster have increasingly become a major issue in the international agenda.

Throughout history and in stories from many lands, disasters have been interpreted as the catastrophic inner self of the planet. However, as a result of the significant shifts of scientific paradigms and a major understanding of the various spheres of interactions among nature and society, scientific thought has come to regard the unnaturalness of disasters as a more correct line of reasoning. Disasters are not natural (Maskrey 1993); they are configured by socioeconomic, historical and cultural processes linked to development and, above all, they are sculpted by the infinite dimensions of vulnerability (for example, see Blaikie et al. 1994; Burton 1997; Burton et al. 1978; Hewitt and Burton 1971; Oliver-Smith and Hoffmann 1999; Winchester 1992).

While the late 1960s saw some investigations that addressed the significance of vulnerability in the understanding of risk and disasters, it was the first decade of the twenty-first century when inquiries into disaster really stressed the social context and the different aspects of vulnerability as the key elements for risk management, integrated risk research and prevention and mitigation of disasters (for example, see Cannon 1993; Cutter 1996; Pelling 2003; Wisner et al. 2004).

2.2 On the Significance of Small- and Medium-Scale Disasters

Large, moderate and small-scale disasters are usually defined by quantitative factors rather than by qualitative analysis. This is therefore not surprising that the exceptional numbers of deaths, affected people and economic impact can be part of the definition of large and hence the most important disasters. However, small and moderate disasters too may have serious consequences in daily life, although their significance may not be appreciated if insufficient attention is paid to the prevailing and historically determined social and economic conditions, people's perceptions and capabilities and needs. In this way, the underestimation of their significance may impede resilience, development, sustainability and adequate disaster risk management.

Studies by La RED (Network for Social Studies on Disasters Prevention in Latin-America) have pointed out the need to evaluate the impact of small- and medium-size events, since accumulated effects are at least as important as those linked to large disasters. Indeed, both small- and large-scale disasters contribute extensively to the persistence of, or increase in, poverty (Lavell 2008; Velásquez and Rosales 1999). In this respect, for instance, research in Africa on disasters and urban development has indicated that as population and vulnerability rise in areas with an intensification of hazards, the number, territorial extent and impact of small-scale disasters rapidly increase, meaning that small events may in fact develop in time into larger events. The ability to prevent larger disasters may in this sense be enhanced through the experience gained by interventions to prevent small disasters, and this should be a major focus of risk management (Bull-Kamanga et al. 2003). Additionally, analysis in Colombia (Marulanda et al. 2010) has suggested that small events derived from socio-natural processes linked to environmental deterioration may pose a significant development problem at both the local and national scales. While this is not considered at the international level, such small events are responsible for the spatial variability and dispersion of risk.

As disasters result from unresolved problems of development (Maskrey 1989), attention must be given to any type and size of event that may impede or even counter-progress development at all scales. Indeed, disasters are generated at global and national levels, as well as at regional and local levels. Within local contexts, and even more pertinently at the household scale, the consequences for development are very important because they play a significant role in determining one's vulnerability and/or resilience.

3 Disaster Impact and Early Warning Systems

Disaster losses and mortality over the last 20 years suggest that the need for EWASs is acute. According to the United Nations Office for Disaster Reduction (UNISDR), the estimated impact of disasters worldwide has included 1.3 million deaths, 4.4 billion affected people and economic losses of US$2 trillion since 2012 (UNISDR 2012). Large and small countries, developed and developing nations, have all suffered such consequences. For example, 2.2 billion inhabitants were affected by disasters in China and the economic losses in the USA were as high as US$560 billion (without considering the impact of the storm Sandy) (UNISDR 2012). Not surprisingly, worldwide statistics show that more than 90 % of the fatalities caused by disasters associated with natural hazards occur in developing countries. The most recent data show that disasters have become more frequent over the past two decades, but the average number of affected people has decreased from 1 in 23 in 1994–2003 to 1 in 39 during 2004–2013. Population growth is partly responsible for this decline, but there is also a decrease in absolute terms. However, death rates have increased over the same period, averaging more than 99,700 deaths per year between 2004 and 2013 (EM-DAT 2015).

Before Hurricane Katrina in 2005 in New Orleans and on the Gulf Coast, disasters had been seen as inextricably linked with poverty in the developing world. It is now clear that although disasters usually hurt the poorest people most, their impact is not exclusively concentrated in the most socio-economically deprived nations (Blaikie et al. 1994; Cannon 1994). Developed and non-developed countries are vulnerable in different ways to hazards, both natural and human induced (Alcántara-Ayala 2002).

In recent years, human and economic losses due to disasters associated with the use of EWS rose dramatically as a result of the Indian Ocean Tsunami in December 2004, Hurricane Katrina in 2005, the Tōhoku Earthquake in 2011, the extensive floods in Thailand also in 2011 and Hurricane Sandy in the USA in 2012. These disasters demonstrated vulnerability in both developing and developed countries, but most notably in nations such as Japan where progress in a culture of disaster prevention and in structural and non-structural mitigation had been considered to be among the most effective in the world. What is more, this series of disastrous events brought to light a relatively new concern regarding the economic impact of high-magnitude global disasters and the resultant challenges for development.

In just a decade, the new millennium has shown that major disasters can take place in the "developed world" and consequences are beyond international and continental borders. Multiple hazards, risk and most importantly the expanding dimensions of vulnerability within the sphere of risks have proved to determine everywhere the magnitude of disastrous events. On this basis, and having no intention of undermining the significance of small- and medium-scale disasters, some of the most significant disasters that have occurred with a global impact in the past decennium are presented in this section.

3.1 The Indian Ocean Tsunami, 2004

On 26 December 2004, a tsunami originating in the Indian Ocean travelled at high speed around the globe (see Table 7.3). A 9.1-magnitude earthquake at a depth of 30 km occurred along the interplate thrust separating the oceanic India plate from the overriding Burma (Andaman) microplate that borders the larger Sunda plate (Geist et al. 2007). This produced a tsunami with heights of 30 m, run-ups of as high as 50 m a.s.l. and reaching 6 km inland (Paris et al. 2007). A 1200 km fragment of the seafloor was moved, and the energy released was comparable to that of 550 million Hiroshima atomic bomb explosions (Tsunami Global Lessons Learned Project 2009).

The aftermath involved more than 228,000 fatalities in 14 countries, including 40 nationalities in the Southeast Asia and South Asia regions, and even in regions as distant as Africa. The largest group of fatalities by percentage were women, followed by elderly and children. Human losses were highest for poor people. Economic damage accounted for US$10 billion (Tsunami Global Lessons Learned Project 2009). People displaced were estimated at >1.7 million. Coastal

Fig. 7.1 Gleebruk Village, district of Aceh Besar, southwest of Banda Aceh, Indonesia, before (*left*) and after (*right*) the 2004 Tsunami (Digital Globe, Imagery collected 12 April 2004)

communities, fishing, small-scale agriculture, infrastructure, private assets and tourism were considerably affected. According to estimates by the Asian Development Bank (ADB), the tsunami has resulted in two million people at risk of deeper impoverishment. Although losses were mainly of uninsured private assets, estimates of insurance pay-outs range from US$2.5 to 5 billion (Inderfurth et al. 2005).

Environmental assessments undertaken immediately after the event revealed widespread and varied damage to the natural resources, including coral reefs, mangroves, sand dunes, peat swamps and other coastal ecosystems (Fig. 7.1). Consequences for the environment derived mainly from the impact of debris, coastal erosion and depositional processes on reefs, agriculture land and rivers. This damage reflects the function of these coastal systems as the first line of defense against the tsunami. Inland waters, wetlands and agricultural land were salinized and groundwater contaminated with hazardous waste (UNEP 2006).

However, the response to the tsunami also had some positive outcomes. For example, 2 years later in Sri Lanka, the event was a catalyst for the foundation of the Ministry of National Disaster Management and Human Rights. On the same day as the tsunami, the Government of the Maldives established a National Disaster Management Centre as a coordination mechanism for disaster-related activities (Tsunami Global Lessons Learned Project 2009).

One of the most significant impacts of the devastating tsunami was the transformation of the event into a consciousness-raising mechanism for the international community; the special sessions of the 2005 second World Conference on Disaster Reduction (WCDR) in Kobe, Japan, focused attention on the disaster and on the need for EWS, public awareness and education, structured coordination, community-based approaches to DRR and multi-disciplinary work.

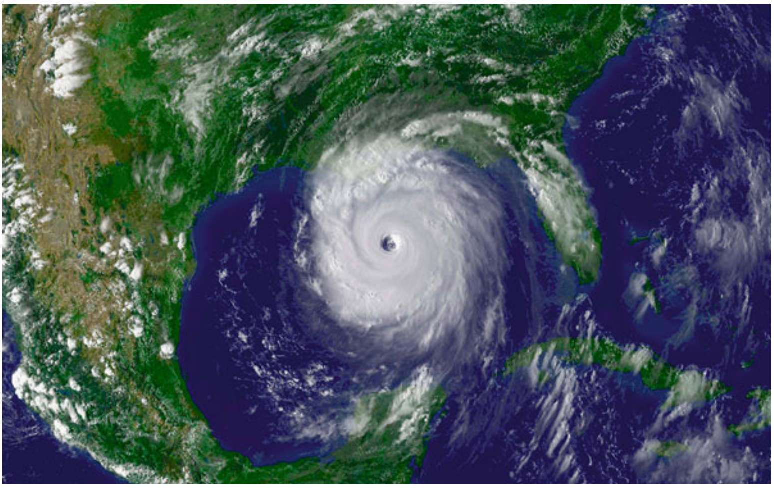

Fig. 7.2 Hurricane Katrina, 28 August 2005 (Source: NOAA, 2005)

3.2 Hurricane Katrina, 2005

According to the technical report by NOAA's National Climatic Data Center (Graumann et al. 2005), Hurricane Katrina (Table 7.3, Fig. 7.2) was the most costly disaster and one of the deadliest ever to strike the USA. From a meteorological perspective, the hurricane, a category 3, when it made landfall was also one of the most powerful storms to impact the coast of the USA during the past 100 years, with 127 mph winds. Effects included extensive and substantial devastation along the central Gulf Coast states, catastrophic floods in New Orleans and the displacement of more than 250,000 people. The aftermath involved over 1,800 deaths, 500,000 people affected and total damages of US$125 billion (EM-DAT database).

As a storm surge overcame the protective floodwalls of New Orleans, 80 % of the city was flooded. Buildings were considerably damaged by intense winds and torrential rains. In Louisiana, Mississippi and Alabama, more than two million people had no electricity, and more than half a million were left homeless. More than 1,200 fatalities were associated with the failure of the dikes, the storm surge, wind and rain (Congleton 2006).

Flooding in New Orleans under storm conditions, that is, a storm stronger than a category 3 hurricane, was predictable. The topography of a city located mostly below sea level, with no natural drainage, was clearly an ideal template for floods to take place. Canal and pumping networks had been implemented to control flooding, but maintenance of floodwalls and levees had not been a priority. Infrastructure capability and thresholds were thus exceeded by Katrina.

The disaster was complex. In addition to the susceptibility of the infrastructure, other factors contributed to the condition of risk. Oliver-Smith (2006) suggested that the complexity of the impact of Hurricane Katrina on New Orleans stemmed from an excessive dependence on technological protection combined with an assault on the natural defences of the environment of southern Louisiana. This gave rise to a very vulnerable city, whose population was displaced and challenged economically, socially and psychologically. Vulnerability was therefore at the root of the uneven impact of Hurricane Katrina on the inhabitants of New Orleans. Flood damage pervaded the city quarters irrespective of income, ground height and other social factors. However, pre-existing socio-economic conditions determined the ability of specific economic classes, and thus racially defined and other groups, to react to conditions during the response and recovery phases. Not surprisingly, those with the fewest resources and the least mobility suffered the most in the aftermath (Masozera et al. 2007).

The effects of Hurricane Katrina mirrored the historically constructed issues and multifaceted relationships of racism, classism, gender issues and aging (Levitt and Whitaker 2009). In spite of the accurate scenario provided by Laska (2004), this was in a nation that in the minds of many natives and outsiders, including the disaster authorities at local, state and federal levels (i.e. FEMA), had not been previously considered to be as vulnerable to such serious losses in disasters.

3.3 The Tōhoku Earthquake, 2011

On 11 March 2011, 62 municipalities in the prefectures of Aomori, Iwate, Miyagi, Fukushima, Ibaraki and Chiba in north-eastern Japan were severely damaged by the tsunami triggered by the Heisei Tōhoku 9.0 magnitude earthquake (MLIT 2011), also known as the Great East Japan Earthquake (see Table 7.3). It was a plate-boundary thrust-faulting earthquake that occurred in the subduction area with a reverse fault, a depth of 24 km, and a fault area extending 400 km and 200 km in the NS and EW directions, respectively (Headquarters for Earthquake Research Promotion 2011; Mimura et al. 2011). The Geographical Survey Institute of Japan (2011) indicated that the seismic activity was linked to a large movement of the crustal plate, including 4.0–5.0 m horizontal offshore movement and 0.4 to >1.0 m subsidence; the largest ground movement was observed at the Ojika Peninsula, Miyagi Prefecture, with 5.4 m horizontal and 1.20 m vertical movements (Mimura et al. 2011).

Tsunami waves recurred seven times during the 6 h after the earthquake, with the third being the highest. Heights varied spatially (see Table 7.1). At Ōfunato, heights up to 24 and 30 m were reported by the Port and Airport Research Institute and by a group of academic researchers from Yokohama National University and the University of Tokyo, respectively. Moreover, at Tarō, Iwate, a researcher from the University of Tokyo estimated a tsunami height of 37.9 m (Takeuchi and Chavoshian 2011).

Table 7.1 Tsunami wave height measured by offshore telemetry by the Port and Airport Research Institute

Place	Tsunami wave height (average) (m)
Port of Hachinohe	5–6
Port of Hachinohe area	8–9
Port of Kuji	8–9
Mooring GPS wave height meter at offshore of central Iwate (Miyako)	6
Port of Kamaishi	7–9
Mooring GPS wave height meter at offshore of southern Iwate (Kamaishi)	6.5
Port of Ōfunato	9.5
Run-up height, port of Ōfunato area	24
Mooring GPS wave height meter at offshore of northern Miyagi	5.6
Fishery port of Onagawa	15
Port of Ishinomaki	5
Shiogama section of Shiogama-Sendai port	4
Sendai section of Shiogama-Sendai port	8
Sendai Airport area	12

Source: Takeuchi and Chavoshian (2011)

Five aftershocks with magnitudes greater than 7.0 Mw and hundreds larger than 5.0 Mw followed the main event. The Tōhoku event was a complex multi-disaster with a chain reaction caused by seismic activity: the tsunami, floods, land subsidence, landslides and radioactive fallout from the Fukushima Daiichi Nuclear Power Station of the Tokyo Electric Power Company (TEPCO). As all power sources of TEPCO were lost, damage to the reactor cooling system and fuel disposal storages threatened inhabitants and workers in the area for several days through the diffusion of radioactive substances throughout the vicinity. Level 7 of the International Nuclear Event Scale (the same level as Chernobyl) was reached (MLIT 2011; Takeuchi and Chavoshian 2011).

Despite the existence of tsunami dikes, the surging waters overtopped tsunami thresholds and caused major damage. Structures at TEPCO designed for protection against a tsunami were 5.7 m high; however, the tsunami wave reached 15 m. Around 1,000 lives were lost because people sheltered in evacuation centres that were at an insufficient height relative to the height of the tsunami (Takeuchi and Chavoshian 2011).

The inundation extended over 561 km^2, with Ishiniomaki and Rikuzen-Takata being among the most devastated areas (Table 7.2). Seventy-six thousand houses collapsed and were washed away, with a further 244,000 partially damaged. Basic infrastructure including electricity, water supply, sewage systems and gas lines were also affected (Mimura et al. 2011). According to the National Police Agency of Japan (2015), direct damage included 4198 roads, 116 bridges, 29 railways, 45 broken dikes and 207 landslides. The debris from the destruction of buildings in Iwate, Miyagi and Fukushima were estimated at 22,600,000 tons (MLIT 2011).

Table 7.2 Examples of height and areas of inundation due to the tsunami, and the resulting human toll

Place	Inundation height (m)	Inundated area (km^2)	Area inundated (%)	Residential area inundated (%)	Dead and missing people	Rate of dead and missing people (%)
Rikuzen-Takata	15.8	13	5.6	43	2422	10.4
Kamaishi	9.3	7	1.6	22	1310	3.3
Otsuchi	12.6	4	2.0	52	1631	10.7
Ishiniomaki	15.5	73	13.1	46	5538	3.5
Onagawa	14.8	3	4.5	48	1504	15.0
Minamisanriku	15.9	10	6.1	52	1095	6.3

Source: Japan Weather Association, 2011 and Disaster Countermeasures Office, 2011, in Mimura et al. (2011)

Fig. 7.3 Devastation caused by the tsunami in the City of Ishinomaki, Miyagi, where the highest percentage of fatalities occurred (photo courtesy: Kuniyoshi Takeuchi, 2011)

The Tōhoku disaster included 19,846 fatalities, some 368,820 people affected, economic damages reaching US$210 billion (*EM-DAT*-Database) and the evacuation of 468,000 persons. Some 52,000 residents were still being sheltered 4 months after the earthquake (MLIT 2011). The highest concentration of human losses occurred in the prefectures of Miyagi (Fig. 7.3), Iwate and Fukushima. The largest numbers of deaths occurred among the elderly and women, and >90 % of deaths were due to drowning (MLIT 2011; Takeuchi and Chavoshian 2011).

The magnitude of the Tōhoku event constituted an unexpected complex multi-disaster that devastated Japan, despite being the country whose disaster preparedness and awareness had been the best in the world. Nevertheless, traditional knowledge on levels of tsunami wave height had not taken into consideration. Unquestionably, lessons learnt by Japanese society through the experience of this tragedy must contribute to a better understanding of the vulnerabilities present in supposedly “resilient” societies. The concatenated risks associated with environmental impacts will thus have to be re-evaluated.

These cases clearly demonstrated the need for EWASs. In each case, more articulated EWSs could have proved crucial in reducing the loss of life, environment and property. In addition to the scientific uncertainty, social factors restrained the delivery of crucial information. The lack of a tsunami EWS with concomitant articulations with social institutions had tragic consequences for exposed and vulnerable people in the many nations affected by the tsunami of Southeast Asia in 2004. Without question, the socially constrained distribution of information on risk and evacuation doomed hundreds of elderly and African-American citizens in the USA. In Japan, the failure to take into account traditional knowledge of tsunami risk, evidenced by the existence of nineteenth-century stone marker warning of tsunami levels, led to the exposure of people and infrastructure (Fig. 7.4 and Table 7.3).

Fig. 7.4 Traditional knowledge: Japanese stone marker for tsunami warning at Miyako City, Iwatake Prefecture, “High dwellings are the peace and harmony of our descendants and will be safe. Do not forget the disaster of the great tsunamis. Do not build any homes below this stone (1896)”

Table 7.3 Characterization of selected "large" disasters during 1900–2011

	Disaster	Indian Ocean tsunami	Hurricane Katrina	Tōhoku earthquake and tsunami
Disaster aftermath[a]	Countries affected	(a) Indonesia (b) Sri Lanka (c) India (d) Thailand	USA	Japan
	Date	26/12/2004	29/08/2005	11/03/2011
	Fatalities	(a) 165,708 (b) 35,399 (c) 16,389 (d) 8,345	1833	19,846
	Total affected people	(a) 532,898 (b) 1,019,306 (c) 654,512 (d) 67,007	500,000	368,820
	Economic damage (US$000)	(a) 4,451,600 (b) 1,316,500 (c) 1,022,800 (d) 1,000,000	125,000,000	210,000,000
Socio-economic and environmetal indicators[b]	Human Development Index (HDI) 2011	(a) 0.617 (*R*: 124) (b) 0.691 (*R*: 97) (c) 0.547 (*R*: 134) (d) 0.682 (*R*: 103)	0.910 (*R*: 4)	0.901 (*R*: 12)
	People in severe poverty (%)	(a) 7.6 (b) 0.6 (c) 28.6 (d) 0.2	NA	NA
	People living on degraded land (%)	(a) 3.1 (b) 21.1 (c) 9.6 (d) 17.0	1.1	0.3
	Quality of life (2011)	(a) 0.591 (*R*: 78) (b) 0.570 (*R*: 81) (c) 0.489 (*R*: 100) (d) 0.605 (*R*: 71)	0.806 (*R*: 31)	0.882 (*R*: 13)
	Health	(a) 0.499 (*R*: 92) (b) 0.658 (*R*: 62) (c) 0.452 (*R*: 96) (d) 0.666 (*R*: 56)	0.770 (*R*: 39)	0.907 (*R*: 3)

(continued)

Table 7.3 (continued)

	Disaster	Indian Ocean tsunami	Hurricane Katrina	Tōhoku earthquake and tsunami
	Education	(a) 0.809 (*R*: 72) (b) 0.806 (*R*: 74) (c) 0.492 (*R*: 116) (d) 0.824 (*R*: 60)	0.941 (*R*: 22)	0.946 (*R*: 14)
	Wealth	(a) 0.463 (*R*: 91) (b) 0.450 (*R*: 92) (c) 0.437 (*R*: 97) (d) 0.560 (*R*: 71)	0.818 (*R*: 20)	0.788 (*R*: 28)
	Democracy	(a) 0.696 (*R*: 58) (b) 0.456 (*R*: 85) (c) 0.734 (*R*: 54) (d) 0.417 (*R*: 90)	0.964 (*R*: 15)	0.891 (*R*: 32)
	Environment	(a) 0.344 (*R*: 113) (b) 0.653 (*R*: 51) (c) 0.413 (*R*: 104) (d) 0.633 (*R*: 59)	0.651 (*R*: 52)	0.766 (*R*: 18)

Sources: [a]EM-DAT database, [b]UNDP 2011 and Quality Life Index 2011

4 Early Warning Articulated Systems: An Integrated Approach

4.1 On the Definition of Early Warning Systems

Derived from the impact of large disasters, especially after the tsunami of Southeast Asia, particular attention has been given to the establishment and/or evaluation of EWS at international and national levels. EWS is defined as “the provision of timely and effective information, through identified institutions, that allow individuals exposed to hazards take action to avoid or reduce their risk and prepare for effective response" (UNISDR 2006). EWSs should be integrated by four major elements: risk knowledge, monitoring and predicting, dissemination of information and response (UNISDR 2006). Further recommendations from the United Nations Office for Disaster Reduction (UNISDR) include the development of a globally comprehensive EWS, rooted in existing EWSs and capacities; building national people-centred EWSs; filling the main gaps in global early warning capacities; strengthening the scientific and data foundations for early warning and developing the institutional foundations for a global EWS response (UNISDR 2006).

Based on the recommendations made by the UNISDR (2006), different warning systems have been established around the world. Despite having the same objective, namely reducing loss of lives and livelihoods, warning systems are designed and put into practice in very different ways. They vary from specific local needs to regional challenges, and in particular, they are quite frequently technical or hazard centred, leading to the question of what is actually missing from the current EWS framework.

Focusing on response rather than prevention when defining EWS perhaps inhibits the development of an integrated approach. Preparedness and risk management go beyond providing and receiving "real-time" information to take action within the traditional agenda of EWSs. Undoubtedly, warning systems aim at cautioning people, alerting and giving notifications about the occurrence of a given hazard and its likely impact so that it can be reduced. However, attention has not been given in a compulsory manner to basic questions, such as how can people be expected to know exactly what to do, when and most importantly why.

The first decade of the new millennium has demonstrated that major disasters can take place not only in the developing but also in the developed world. Indeed, consequences from disasters have no geographical borders. Within the sphere of risks, the expanding dimensions of vulnerability even of resilient societies have proved to determine the magnitude of disastrous events at all scales in space and time. If EWSs are intended to reduce or avoid human, economic and environmental losses, why are vulnerability and resilience not more commonly taken into account? Generally, the implementation of EWSs is concentrated on providing "real-time" information in order to respond, rather than enhancing the knowledge and preparedness to understand risk and thus reduce it. The answer to that question is not that simple, and indeed relates to all elements and complex interactions that need to be considered for DRR and DRM. Nonetheless, it can be pointed out that for the specific case of implementing effective and efficient EWASs, uncertainty, integrated science, communication and governance are the upmost essential ingredients.

4.2 Uncertainty

Uncertainty is a situation in which something is not known or certain. According to the Senior Seismic Hazard Analysis Committee (SSHAC), uncertainty can be divided into aleatoric uncertainty and epistemic uncertainty (SSHAC 1997). Aleatoric uncertainty, also called irreducible uncertainty, involves the intrinsic randomness of a phenomenon. It refers to the inherent uncertainty due to probabilistic variability. Epistemic uncertainty, more subjectively and professionally related, derives from the lack of knowledge of many sorts, including the inadequate understanding of underlying processes, incomplete knowledge of phenomena or a non-accurate assessment of the related characteristics. Knowledge is limited and operational modes are not known. As such, in contrast with the aleatory uncertainty, epistemic uncertainty is reducible. In this sense, producing or gathering more information would help to reduce epistemic uncertainty.

Disaster risk involves both aleatorial and epistemic uncertainties. Aleatory uncertainty is the inherent uncertainty of the hazard itself, while epistemic uncertainty is closely linked to hazard assessment in terms of modelling limitations. To this regard, the latter comprises of three components: parametric uncertainty—derived from deficient knowledge of the settings of the model's parameters, input uncertainty—resulting from incomplete knowledge of the true value of the initial state and forcing and structural uncertainty—of which, despite the knowledge of correct parameters and inputs, the model fails to represent the system (Hill et al. 2013).

Epistemic uncertainty is interrelated with the limitations of resources, information, understanding and knowledge. Therefore, it is not only related to the hazard, but above and beyond all, it is also related to the way people act, behave and take decisions. It is indeed this kind of uncertainty associated with actions and decision-making processes that are the most significant for EWAS. Epistemic uncertainty, in this sense, plays a very significant role in DRR and DRM.

4.3 Integrated Science

Scientific and technological developments have certainly led to the achievement of various aspects of social progress. However, the role of science and technology for DRR policies remains questionable, as losses and affected populations continue to rise worldwide (Cutter et al. 2015). In this regard, international efforts have been made to discuss the complexity of and achieve DRR and DRM by organizing major international events linked to global strategies, such as the World Conferences on Disaster Reduction in Yokohama (1994), Hyogo (2005) and Sendai (2015) in Japan (UNISDR 2005a, b). As an antecedent to the disaster reduction agenda, in 1992 the UN Framework Convention on Climate Change (UNFCCC) was signed, and among other commitments envisaged the social consequences of response strategies to the impacts of climate-related hazards on communities. The 2002 World Summit on Sustainable Development and the related Millennium Development Goals also considered various commitments by governments comprising "an integrated, multi-hazard, inclusive approach to address vulnerability, risk assessment and disaster management, including prevention, mitigation, preparedness, response and recovery, is an essential element of a safer world" (UNDESA 2002).

Additionally, the International Council for Science suggested the establishment of a science programme on Integrated Research for Disaster Risk (IRDR). IRDR, a global, trans-disciplinary research programme aims at addressing the major challenges of natural and human-induced environmental hazards, which entails a full integration of research expertise from all disciplines: natural, socio-economic, health and engineering sciences, in addition to the sphere of practice including policy-making, risk communication and public and political perceptions of and responses to risk. Within a framework built by positioning capacity building, case studies and demonstration projects show assessment, data management and monitoring as the three cross-cutting themes. The main objectives of the programme are (a) characterisation of hazards, vulnerability and risk; (b) understanding decision-making in complex and changing risk contexts and (c) reducing risk and curbing losses through knowledge-based actions (ICSU 2008).

Particular goals to address IRDR research objectives involve the following (IRDR 2013):

1. *Promoting integrated research*

Develop and promote integration and collaboration within the disaster risk reduction community to avoid unnecessary duplication and to maximise research outcomes.

2. *Characterizing hazards, vulnerability and risk*

Identify hazards and vulnerability leading to risks from natural hazards on global, regional and local scales; develop the capability to forecast hazard events and assess risks as well as the dynamic modelling of risk.

Address the gaps in knowledge, methodologies and types of information that prevent the effective application of science to avert disasters and reduce risk.

3. *Understanding decision-making*

Understand effective decision-making in the context of risk management—what it is and how it can be improved; identify relevant decision-making systems and their interactions; understand decision-making in the context of environmental hazards and help improve the quality of decision-making practices.

4. *Reducing risk and curbing losses*

Develop a methodology for implementing comprehensive, long-term vulnerability assessments and effective approaches to risk reduction by bringing together insights gained under Goals 2 and 3.

5. *Networking and partnership building*

Develop, strengthen and collaborate within the IRDR network at global, regional and national levels.

6. *Supporting the science and policy dialogue*

"Enhance the utilization of research findings" (IRDR 2013, pp. 7–13).

To achieve such challenging goals, IRDR is focussed on four major projects directed towards information dissemination, networking and collaboration fora: Assessment of Integrated Research on Disaster Risk (AIRDR); Disaster Loss Data (DATA); Forensic Investigations of Disasters (FORIN) and Risk Interpretation and Action (RIA). AIRDR concerns the global network of researchers involved in the first systematic and critical global assessment of integrated research on disaster risk, whereas DATA is centred in a growing network of stakeholders from different disciplines and sectors to study issues related to the collection, storage and dissemination of disaster loss data. FORIN is a methodology that investigates the underlying causes of disasters. RIA is concentrated on understanding how people, both decision-makers and ordinary citizens, perceive, interpret and make decisions, individually and collectively, regarding the risks (IRDR 2013).

4.4 Risk Communication

Communicating uncertainties and particularly communicating risk remains a major challenge. According to the US National Research Council, risk communication can be regarded as "an interactive process of exchanging of information and opinion among individuals, groups, and institutions. It involves multiple messages about the nature of risk and other messages, not strictly about risk, that express concerns, opinions, or reactions to risk messages or to legal and institutional arrangements for risk management" (National Research Council 1989).

Quite frequently the term risk communication is misinterpreted and therefore misleading. Communication within most of the common existing EWS frameworks refers to the transmission of information concerning specific circumstances or a determined event so that people can take action as a response to imminent warnings. However, the notion of risk communication needs to go beyond that apparel and rely on the understanding of how risk is a construction itself, and therefore cannot be purely based upon the certainty of existing uncertainties, in terms of both hazards and vulnerability. There is thus great value of risk perception and the influence of governance issues in the decision-making processes around risk management.

In accordance with the perspective of some researchers (Adam and Van Loon 2000; Campbell 1996; Fischhoff 1995), effective risk communication needs to consider the fact that risk perception is influenced by cultural and societal factors, and does not only focus on biophysical and technological features. Furthermore, and particularly in societies in which there is a high incidence of institutional vulnerability, the effectiveness of risk communication is linked to the social amplification of risk framework (SARF). Such a framework envisages that some aspects of the representation of hazard events interact with different processes, including psychological, social, institutional and cultural elements, and therefore the attenuation (decrease) or amplification (increase) of risk perception can affect behaviors more broadly (Kasperson et al. 1988).

People might overestimate certain risks if institutions neglect the social context of risk during decision-making processes and when delivering information to the public (Rogers et al. 2007). Moreover and contrastingly, exposed groups may also underestimate disaster risk when hazard occurrence does not fit institutional-political agendas at local or national levels, which ultimately means that there is a deficiency in information or that it is not provided accurately. A major and challenging issue is related to the fact that disaster risk is commonly underestimated according to political momenta, and current dimensions of institutional vulnerability are used to legitimise either poor decision-making or the lack of involvement and social responsibilities of authorities and stakeholders.

4.5 Disaster Governance: From Concept to Practice

To secure a safer future for the world within a disaster framework, special attention needs to be paid to disaster governance, which is defined by UNISDR as the entailment of political commitment and solid institutions that can guarantee the success of efficient and sustained DRR by the following means: improvement of DRR as a policy priority; allocation of the resources required for DRR; enforcement of DRR measures and attribution of accountability for failures and assistance for participation by civil society. These aims must be accomplished through policy and planning, legal and regulatory frameworks, resources and organization and structures (UNISDR 2004).

On the other hand, the International Risk Governance Council (IRGC) has established a risk governance framework aimed at advising risk governance institutions to recognize not only the need to consider knowledge about hazards, but also the concerns that people associate with the different causes of risks. This interdisciplinary and multi-level governance approach fully accounts for the societal context of both the risk and decision-making, and comprises of five phases: (1) pre-assessment, (2) appraisal, (3) characterisation and evaluation, (4) management and (5) communication (IRGC 2008).

At a local scale and based on some case studies, the United Nations (2010) has acknowledged four major roles of local governments for achieving DRR that reflect the significance of disaster risk governance:

1. "To play a central role in coordinating and sustaining a multi-level, multi-stakeholder platform to promote disaster risk reduction in the region or for a specific hazard.

2. To effectively engage local communities and citizens with disaster risk reduction activities and link their concerns with government priorities.
3. To strengthen their own institutional capacities and implement practical disaster risk reduction actions by themselves.
4. To devise and implement innovative tools and techniques for disaster risk reduction, which can be replicated elsewhere or scaled up nationwide" (United Nations 2010, p. IX and X).

Quite commonly, concepts of risk governance clearly identify the totality of actors, rules, conventions, processes and mechanisms that need to be involved in data collection and analysis, communication and decision-making, in addition to the necessity of taking into account factors associated with particular contexts including institutional arrangements, political culture and risk perceptions (IRGC 2005). What is more, risk governance is also seen as the means by which "authorities, public servants, media, private sector, and civil society coordinate in communities and on regional and national levels in order to manage and reduce disaster and climate related risks" (UNDP 2013). These interactions are also expressed as the intersection between horizontal and vertical governance (Benz and Eberlein 1999; Lyall and Tait 2004). The first one consists of the relevant actors for decision-making based on a specific geographical or functional segment, whereas the latter refers to the linkages between those segments (Aven and Renn 2010).

Notwithstanding the significance of such critical, although still idealistic suggestions, disaster risk governance urgently needs to move towards application and practice.

Despite the role of international and global institutions such as the United Nations and the World Bank, disaster governance relies on state and local based actions. Although it is widely accepted that population growth, especially in cities and megacities, increases potential losses and challenges to governance, and that disaster governance is polycentric and multi-scale (Tierney 2012), DRR and DRM within sub-national and local contexts vary across countries, even in rural areas. Consequently, mechanisms, risk communication, coordination, decision-making and actions are not delineated adequately in terms of the conceptual structure of disaster risk governance. Financial, legal and organisational frameworks are politically dependant; thus transforming political borders and the interests of political parties within nations to focus on societal needs, territorial management and environmental equilibriums are priorities, but transformed into obstacles for integrated, effective and efficient action.

5 Concluding Remarks

Human and economic losses due to disaster associated with EWSs have skyrocketed significantly in recent years owing to the severe impact of the Indian Ocean Tsunami in December 2004, Hurricane Katrina in 2005, the Tōhoku

Earthquake in 2011, the extensive floods in Thailand also in 2011 and Hurricane Sandy in the USA in 2012. Such disasters have unveiled dimensions of vulnerability in all types of countries, but especially in nations such as Japan where their culture of disaster prevention and of structural and non-structural mitigation had been depicted as one of the best in the world. These series of disastrous events have also given rise to major and relatively new concern regarding the economic impact of high-magnitude global disasters and the consequent challenges for development.

The Tōhoku event for instance can be regarded as an unprecedented complex multi-disaster that devastated Japan and changed the perception of preparedness for the rest of the world. Lessons learned from this disaster include the pressing need to gather historical data and traditional knowledge on both hazards and vulnerability for EWASs. From the perspective of natural hazards, uncertainties of models and understanding of processes and mechanisms should be reconsidered, because established or expected thresholds have dramatically been exceeded. Dependence on technology has to be questioned, because disastrous events frequently threaten, damage and disrupt food supplies, water resources, electricity, transport, accessibility and communication systems. Indubitably, the Japanese experience would contribute to a better understanding of the vulnerability of resilient societies and the concatenated risks associated with environmental impacts will have to be revaluated. These signals stress the urgent need to adopt agreed and coordinated measures and policies that take a big step forward into the inclusion of the multiple dimensions of vulnerability of societies in EWASs.

The impact of small, medium and large disasters on economies and economic systems of production, and hence on the global economy, needs to be examined, and economic structures probably re-evaluated. In both developed and developing countries, societal response, organisation and recovery should be defined in terms of the dynamism of vulnerable groups that are classified by age, gender, religion, education level or psychological strengths and weaknesses for the design of EWASs. People's awareness would have to be further developed on the basis of experiences derived particularly from the latest disasters and would need to be fortified with knowledge concerning hazards and vulnerabilities. The challenge of DRR should, in this sense, probably be centered, above all, on the significance of disaster consequences as learning mechanisms for building resilience, decreasing vulnerability and achieving sustainable development.

EWASs (Fig. 7.5) should be sound processes that sustain the practices of close and continuing partnerships among communities, scientists, authorities, decision makers, stakeholders and every actor involved in the construction of risk. They should also be characterized by a responsible commitment to achieving and guaranteeing DRR and DRM in space and time. EWASs should be based on disaster risk-integrated science within a legal and ethical framework on which multi-directional and permanent risk communication plays a central role in the construction of a culture of a risk conscious society. It is not exclusively intended to serve as a coordinating system of response, but most importantly is directed towards the comprehension of disaster risk by incorporating the understanding of root causes of disasters, risk perception and the different dimensions of vulnerability,

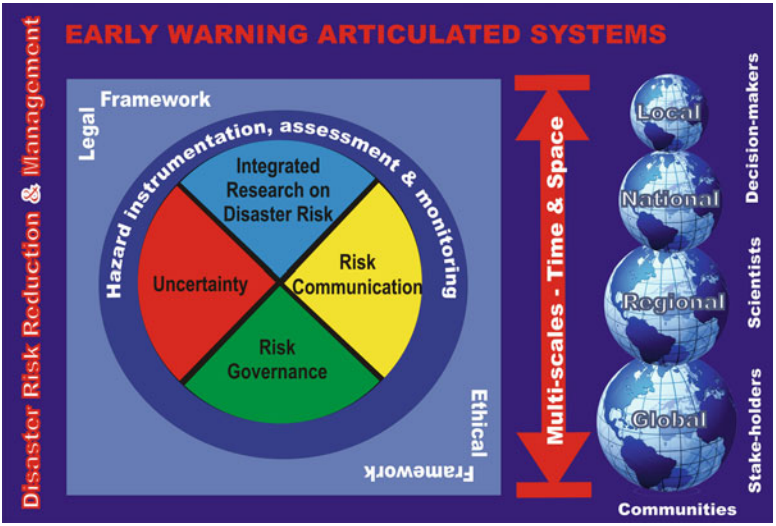

Fig. 7.5 The structure of early warning articulated systems (EWAS)

resilience and adaptation. It must also be structured as a capacity-building progression that allows people to recognize the social construction of disaster risk and its potential consequences in order to consider and assess likely disaster scenarios, risk management procedures, realistic measures, response strategies and actions, targeting preparedness, both individually and collectively, but prior to critical time frames. The failure to integrate legally enforced frameworks and ethical codes into EWASs will further exacerbate the incoherence of government policies and practices.

Integrated risk reduction, including the development of sound EWASs, demands crucial and measurable practical implementation of national and international frameworks aimed at and reinforcing the reduction of vulnerabilities and exposure, an increase in resilience and adaptation at local, regional and global scales. This is the key challenge of the present, which is derived from the lessons of the past, in light of the wisdom and desire for a safer and sustainable global future. Yet the prevailing problem of the international and national agendas is the lack of political will and commitment to reducing the vulnerability mosaic at all scales along with fostering resilience and adaptation in societies at risk.

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