Reviewing global development of multi-hazard early warning system with the perspective of its development in Indonesia

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Abstract. Never before a catastrophe brought an influence of the world's attention like the Indian Ocean Tsunami in 2004 (IOT04). Before IOT04, states of the development of Early Warning System technology (EWS) was not as advanced and progressive as it is today. Together with the unavoidable impacts of climate change, disasters - both geologically and hydro-meteorological - are increasingly becoming the mainstream of global concern. Likewise, it's EWS technology. This paper reviews the global development of EWS technologies, both related with geologically and hydro-meteorologically: before IOT04, current, and future development vision. The discussion of UN Agencies in the series of endeavor undertaken to embody Sustainable Development Goal (SDG) 2030 leads to a vision of the future development of EWS technology. Three factors become the primary drivers of EWS progress, among others, the growing awareness of the community that alter the form of a requirement of early warning information, the state of development of information technology, and observational instrumentation. The perspective of its application in Indonesia is also discussed.

1 Introduction

Victims, losses, and damages arising as a result of disaster caused by, among others, the absence of an early warning system (EWS). Natural disasters can occur suddenly (fast onset) such as on geological hazards like an earthquake. Meanwhile, natural disasters caused by hydro-meteorological phenomenon is much more predictable, whether it occurs in a very short onset, such as a small-scale tornado, heavy rain, or others, or longer duration (slow onset) such as the drought.

EWS plays a strategic role to provide an early indication, a timely evacuation and initial information to properly start the preventive action. The EWS becomes very important to mitigate the victims, loss, and damage. The proper function of EWS lies in the pre-disaster phase. Therefore, EWS is required to produce information that is fast, precise, accurate, disseminated broadly and, at the other end, be understandable, particularly by communities at risk.

Before IOT04 that cost more than 200,000 people, the status of EWS, especially on the tsunami, has not received such global attention. After IOT04, an international organization such as WMO (World Meteorological Organization), IOC/UNESCO (International Oceanographic Commission/United Nations Educational, Scientific and Cultural Organization), UNISDR (United Nations International Strategy for Disaster Reduction) and others, develop policy framework on Multi-hazards Early Warning

Systems (MHEWS) in order to realize the vision for the safer future.

The SFDRR (Sendai Framework for Disaster Risk reduction) 2015 placed the EWS as a pivotal element of DRR to materialize the SDG2030. Similarly, to meet the SDG2030, the UNESCO's Medium Term Strategic Plan 2014–2021, in conjunction to coastal hazards, addressed the EWS of seismic and non-seismic tsunamis as one of the strategic factors to anticipate the disasters and mitigating the victim, loss-and-damage. WMO and IOC/UNESCO further agree on the standard platform that will become the foundation of global cooperation to facilitate seamless MHEWS for weather and climate, as well as geo-hazards around the world for 2040.

This paper briefly reviews the global development of EWS in the global perspective. In the first part, the state of EWS before IOT04 is reviewed. In the second part, development of the ten years after IOT04 is discussed. Before concluding remarks, the direction states of EWS development post-SFDRR vision is outlined.

2 Material and methodology

This paper aims at delivering a review of the global development of EWS and the perspective of its development in Indonesia. The report is divided into three sections: before IOT04, its development over ten years after the tsunami, and its future trend of global direction.

The assessment is conducted through literature appraisal. Status of EWS before IOT04 is studied from

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various compilation report related to DRR. There are abundant reports on EWS available in post IOT04. The terminology of EWS has even been thoroughly discussed.

The trend of the future development direction of the EWS, particularly after SFDRR 2015, is summarized from numerous resolutions of WMO, IPCC, and IOC/UNESCO, where the author is actively involved. The decisions of UN bodies which have been agreed upon and supported by member states are presumably becoming the foremost global directive of the future development of EWS and therefore are referred.

3 State of development before IOT04

Before IOT04, the general condition EWS was not as sophisticated as what we perceive today. It took more than 50 minutes to quantify the scale of magnitude of an earthquake, identify the location and depth, as well as the time of occurrence. Not to mention the fracture mechanism and its seismic impact map. The number of seismographs had not as dense as compared with the current situation [1].

Cho [2] and Matveeva [3] indicate that study on EWS as terminology that links to natural disasters emerge and attract global attention after IOT04. Choo [2] noticed that the effectiveness of EWS impliedly showed by two distinct functions, namely, whether (1) it demonstrates the potential hazard of the surrounding, and (2) it raised alert of those who potentially impacted.

UNISDR further describes that an EWS is a set of capacities to generate and disseminate timely and meaningful warnings for the community at risk to act appropriately and in sufficient time to reduce the possibility of harm or loss [4]. Although both [2] and [4] served a systematic definition of EWS, it, however, reiterates the fact that even at the global level, an orderly description came after five years of IOT04.

Before that, a vivid definition EWS is still unclear exist. The Second International Conference on EWS (EWC II) meeting only states a system that can facilitate rapidly to reach the affected site will undoubtedly reduce the risk of casualties and losses [5]. This type of EWS necessitates the cooperation of parties and the integration of public policy, such as spatial planning.

Concerning the EWS, the accord at EWC I in Potsdam in 1998 revealed the need to upgrade the DRR mechanism. The thrust to establish EWS in a more precise definition and led to the establishment of the International Strategy for Disaster Reduction (ISDR). However, it is by far, EWS was still defined in a mere general statement as an essential management tool for risk reduction and vulnerability to natural and technological disasters [4].

Tsunami Warning System in the Pacific (PTWC – Pacific Tsunami Warning Center) in Hawaii under NOAA of USA seemed to be the type of EWS system developed structurally and systematically before IOT04. Further, IOC/UNESCO adopted PTWC as an International Tsunami Information Centre in 1965 to

facilitate capacity building in organizing the EWS, including technology transfer [1].

Laura Kong [1] described that the system was managed by PTWC as part of the daily operation and hosted by the USA Government for international purposes. In 1968, with the initial support of 25 members of states, IOC/UNESCO established an International Coordination Group (ICG) for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS) and assumed a special duty to save victims and property [1].

By 2003, the PTWC's EWS was built based on real-time data based on 100 global seismic observation stations and 100 observations for tsunami monitoring. The system had been able to produce information related to tsunami potential within 20 minutes after the earthquake, much faster than in 1993 which took more than 1 hour to disseminate potential tsunami information after an earthquake occurred [1].

EWS for hydro-meteorologically disaster before IOT204 might not be as sophisticated as that of at PTWC for a tsunami. In the literature, EWS that is admitted as a good example is that of flood prevention in Latin America, Mozambique, and the Mekong River in Vietnam [4]. That EWS is built on the basis of spatial planning management and community awareness support.

Horizontally replication of this system to other location and scale it up requires mass community participatory raises much concerned on its effectivity. Moreover, consideration of economic-cost as compared to the advanced technology application on the spatial-planning management practice has caused disconcerted acceptability of that type of EWS [4]

In Indonesia, before IOT04, an “Early Warning System” (EWS) as known by current terminology has not officially been adopted as part of community awareness and preparedness except the one as part of the daily operation. Instead, the dissemination of the resulted of information, either earthquake or extreme weather, is not intended for evacuation purpose. It only served as the general purpose for daily operational assignments, such as seasonal onset for climate, weather condition, or earthquake occurrence. Even for an earthquake, it needs more than an hour to locate its epic, magnitude, and depth.

In the hydro-meteorological field, an integrated EWS applying an advanced technology system had in fact been made operational on the daily basis by LAPAN (National Space Agency), BPPT (the Agency for the Assessment and Application of Technology) and BMG (the Agency for Meteorology and Geophysics after the occurrence of El Nino in 1997/1998. The system relied on the post-analytical image of NASA's Aqua Terra satellite which maps hotspots at the various area.

Further, those agencies developed the so-called Fire Danger Rating System (FDRS). It delivered an image of the area that easily burned-out based on the various relationship among weather parameters. Those FDRS and hotspot information are used, at least up until at present, as the basis to curb forest fire, especially in the dry season. However, in term of action, the hotspot

information plotted based on the satellite image is, approximately 6 to 12 hours delayed due to satellite regular swept across Indonesia.

The EWS for earthquake and tsunami in Indonesia before IOT04 could be described as the same level as the PTWC system in 1993. Seismic observations were still scarce; the manual mechanism and system constrain the processing. The list of papers presented during EWC II where a report on EWS for earthquake and tsunami in Indonesia was unavailable [3] indicates the condition.

For geo-hazards, instead, Wirakusumah's Paper [6] stated that around that year, the existing Volcanic Hazard Mitigation system was the most developed and sophisticated of EWS type in Indonesia. The system was installed depending on five observational posts. It reported seismic data, visual monitoring of GPS deformation, and other methods. The information was then communicated directly to and assessed by the office of the Volcanology Observatory nearby. The system was proven to successfully observe the process of the increasing level of hazards of the eruption of Merapi Mountain in 2000 till 2001 [6]. It was reported that no one was killed during the eruption. The system was further completed with the construction of sirens, additional of rain-gauge by telemetry and gas detector. It has to be noted that eruption can be considered as "slow" onset as compared to that of the tsunami.

4 Decade after IOT04

Following IOT04, the conditions above changed rapidly. International attention has driven the development of EWS in a more structured and systematic way. It was not only happening for geological disasters, but also for hydro-meteorological ones.

Given the impact of tsunami hazard on society as well as taking into consideration the element of reliability in the information, the level of certainty of an early warning, especially for tsunami, becomes very important. In the years before the 2004 tsunami, early warnings issued could be considered as un-informative [7]. It took more than 45 minutes to generate tsunami forecasts as a result of the earthquake detected [1].

In 2015, ten years after the 2004's tsunami, the condition had shown significant progress. The assurance of information about tsunami potential has been improved almost at the level of thoroughly informative. It is also being used to initiate the evacuation and can be resulted within no more than 15 minutes [7].

However, based on the agreed SOPs, the confirmation of tsunami has still to await the measurement of coastal sea level rise and bottom pressure, even after knowing the location, magnitude, and timing of the earthquake that occurred, including Centroid Moment Tensor (CMT). By the agreed SOP, after 2 hours, if all monitoring processes do not indicate anything correlated with the tsunami, then information of cancelation of the tsunami is issued.

The progress towards the EWS information at the better level of assurance is not without effort. Through ICG of IOC/UNESCO in various regions, a systematic,

coordinated and coherent approach is regularly carried out, both conceptually and practically.

In the Indian Ocean region, as reported by Sakya [8] at the ICG-IOTWMS (Inter -Government Coordination Group for Indian Ocean Tsunami Warning and Mitigation System) meeting, there have been 3 (three) Regional Tsunami Service Providers (RTSP) since 2012, namely Australia, India, and Indonesia. There also are, at least, 2 Working Groups (WG) and 2 Task Teams (TT) within the ICG/IOTWMS which are continuously discussing the progress and development of TEWS (Tsunami Early Warning System) status of each member state, not only at the upstream but also at the downstream parts, respectively.

The WG 1 review the aspects of technology ranging from observational system to the results of information and format. Whereas, WG 2 concerns the downstream part, namely the community side, from the level of understanding on the alert till the post-evacuation evaluation.

The TT 1 assesses the needs and evaluates the capacity development of National Tsunami Warning Center (NTWC). And, the TT 2 conducts preparation of exercise directly at the community level in coordination with other stakeholders through the so-called IOWAVE for the Indian Ocean. In 2016, participants at the community level in the Indian Ocean reaches ~ 60 thousand which were still far as compared with that of CARIBEWAVE16 which involved more than 2 million people. This type of exercise is practiced once in two years.

Meanwhile, once every six months, communication test called CommTest is being conducted to check the reliability of communication connection among member countries. Further, the ICG/IOTWMS also agree on KPI (Key Performance Indicator) that guide every member state to monitor and improve their respective TEWS.

Some of the problems arise from the process of development during the course ten years of EWS after IOT04 are, among others: the accuracy of data, processing speed, standard information format, and - at the other end - how valid the information can mitigate the victims and losses at the potentially impacted area.

In TEWS, Indonesia has installed about 265 seismic sensors and about 150 accelerographs up until the present time. The so-called Ina-TEWS was officially inaugurated in 2008. Indonesia establishes the Ina-TEWS with an advanced system. The process was a breakthrough in the way of its establishment. It involved more than 16 national agencies and five donor countries [9] [10].

After its inauguration in 2008, there have been 20 tsunami warning issued. Six of those 20 warnings were no tsunami [11]. As above mentioned, in 2012 the Ina-TEWS was appointed as Regional Tsunami Provider (RTP) together with Australia and India until today. Through ICG/IOTWMS, the system is regularly monitored and checked either individually or the system of the system among the ICG/IOTWMS members.

The result of warning related to two tsunami occurrences as for illustrative examples can indicate the level performance of the newly established TEWS. The

first was a tsunami in Mentawai happened on 25 October 2010 at 14:42 UTC caused by an earthquake of 7.2SR magnitude and 10 km depth.

It displaced more than twenty thousand people, affected more than 4000 households and cost 435 lives. Upon evaluation of the system, the team concluded that Ina-TEWS worked well as it proofed to disseminate warning within 4 minutes 46 seconds after the first identified earthquake.

It was apparent that the epicenter was too close that a warning seemed too late as the first tsunami wave approached about 5 to 10 minutes to reach the coast. It was then concluded that downstream part – the community outreach – was as not as broad as the coverage of the upstream development [12].

The second event was related with the 8.3SR scale of magnitude of the Wharton Basin earthquake occurred in the 2nd March 2016 at 12:49 UTC. The rapid but thorough evaluation conducted by the Joint Event Assessment comprised of various agencies. The warning mechanism was disseminated through 4 steps of procedures (PDT – Tsunami Early Warning), namely: PDT1 – informing potential tsunami; PDT2 – issuing updated parameters; PDT3 – noting the high wave observed either in the ocean or coastal area, and PDT4 – ending the information of tsunami.

In the case of Wharton Basin tsunami which is approximately 750 Km south-west of Nias Island, there seemed to be no tide-gauge around Indonesia detected the sudden increase of sea surface level caused by the tsunami, especially in the west of Sumatera.

PDT1 and PDT2 were executed well as stated in the SOP. The PDT3 was based on the measurement detected by tide-gauge at Coco Island which took more than the common expectation due to the distant. PDT4 was then issued after 2 hours as required to end the warning of a potential tsunami.

The assessment found that even the system functioned well, the follow-up action that involved other parties seemed to be much less aware. Tsunami rarely occurs, but very impactful. The team thus noted that even though the EWS worked well, however, the follow-up response posed prerequisite the success of an integrated EWS [13].

In the hydro-meteorological field, the disaster perceives to take "longer" time as compared with that of a geological one. The precursor is much more predictable, identifiable as well as observable, either that of resulted through an analytical evaluation based on the observed weather and environmental surrounding condition parameters or assessment using an advanced method, for simple extreme weather such as heavy rain.

Following the success of Ina-TEWS, the government of Indonesia inaugurated Meteorological and Climatological Early Warning System in 2011 and 2013, respectively. The design approach is to replicate that of applied within the Ina-TEWS. Specifically, the upstream part concerns with observation, acquisition, and processing of the parameter related to the natural phenomena, be it weather or climate, to produce needed information, be it a warning or general weather

forecasting or seasonal onset or trend of extreme climate such as ENSO. Technology characterizes the upstream part and thus named as the structural part. The cultural part deals with the response of the community to the information produced by the structural component which is in the downstream section.

Referring to the Law No. 31/2009 on Meteorology, Climatology, and Geophysics, the MHEWS is aimed at delivering information quickly, timely, accurately and broadly as well as understandable. To ensure that that inquiry is fulfilled necessitate telecommunication infrastructure. But, it is the proper response of the people that deliver the critical success of the warning, which is closely related with the level disaster literacy and thus called the cultural part.

What makes hydro-meteorological EWS is somewhat different from the EWS for geological is because of its enormous variety, ranging from heavy rain, floods, landslides, heavy winds, high-wave, storm surge, drought, forest fires, to mention a few.

For example, the further development of participatory hydro-meteorological EWS, either at Mekong River, Mozambique, or Latin America, in fact, combines various type of phenomena, namely, flood for riverine, flash flood for an urban area, coastal inundation at the coastal area, and landslides in the plateau region.

The system is established by integrating the land-based observational stations combined with upper air measurement or remote sensing based. The processing part of this observed data is analyzed to produce 3 to 7 days ahead of prediction for weather, with additional information of potential impact whether flood or landslide or coastal inundation that will soon occur.

In the hydro-meteorological field, WMO is the sole UN body that delivers the reference, the roadmap of guidance in the establishment of EWS in the field of hydro-meteorology [14].

How well the system is functioning, a case of heavy rain and flash "lava" flood due to volcanic ash is brought here for a description. It was approaching midnight when the Mt Kelud in East Java erupted (13 February 2014). During the Cabinet Meeting next day (14 February 2014), the Ina-MEWS presented the process of eruption plume based on Himawari satellite image combined with the 7-day ahead of projected rain in the area of eruption based on WRF^a (Fig. 1). The WRF was part of Ina-MEWS tool.

Fig. 1a shows the volcanic ash plume. Based on numerical simulation made on Feb 13, 2014, heavy rain was predicted pouring in the area of eruption about 1600 HRS local time (0900 UTC) on 18 February 2014 (Fig 1b). The alert was then followed by an instruction order of massive evacuation coordinated by BNPB (National Disaster Management Agency).

^a WRF stands for Weather Research and Forecasting which is a mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting applications and initially developed collaboratively by NCAR, NCEP, FSL, AFWA, NRL, FAA and OU, USA (https://en.wikipedia.org/wiki/Weather_Research_and_Forecasting_Model)

Fig. 1. Result of Himawari satellite image and the 18 Feb's WRF numerical forecast

The heavy rain was as expected exactly hammering the area and triggered an immense of flash “lava” flooding. The result was no single caused of life, though many public buildings, infrastructures and heavy vehicles were damaged and washed away [12].

The Indian Ocean tsunami in 2004 have significantly ignited the progress of development of EWS, not only massively but also more systematic and as well as specific. By 2015, supported by the advancement of information technology, the speed of dissemination as well as coverage, accuracy, properness as well as the timeliness of EWS has conclusively reached significant progress. Within ten years of development, the state of geo-hazards EWS, globally and in Indonesia, has reached a level of an advanced one.

WMO noted two disaster events that started to shift the paradigm of EWS. Those were Tropical Cyclone Fitow in China in October 2013 and TC Haiyan in the Philippine in 2014, respectively [16]. It was admitted that the forecast produced by local National Meteorological Services (NMS), either in China and the Philippine, was very accurate and disseminated timely, however, due to unmeasurable impact, it caused much more loss and damage than expected. Likewise, that of EWS for tsunami, the hydro-meteorological EWS has also been progressively advanced after ten years of IOT04.

5 EWS future development

Every tsunami has its characteristics and cannot be avoided or prevented. But, surely its impact can be

reduced if the warning can be disseminated timely and the level of community preparedness lead to respond to it appropriately. One of the critical issues in efforts to reduce the tsunami risk is to improve the existing TEWS and to map the potential destruction of tsunami inundation.

Regarding distance, tsunamis can be classified into 2 (two) categories: near and far-fields, respectively. IOT04 and tsunami in Sendai 2011 which impacted not only Indonesia and Japan, respectively, can be categorized as far-field tsunami, from the perspective of affected distance. Meanwhile, tsunamis in Mentawai 2010 or those often occur in Hawaii are perceived as near-field tsunamis. The time of arrival of its first wave is too short, but its impact is monstrous.

There are two aspects to be improved. The first is the speed of processing observed data into the warning information and the accuracy and timeliness in disseminating it to the coastal community at risk. The second lies in the effort to leverage the level of preparedness at the community level is “tsunami ready” [17].

The target is to speed up the process of obtaining higher a degree of certainty of information whether an earthquake triggers a tsunami and propagate it to communities at risk. Regarding observations related to geo-hazard is opted to establish an integrated observation system that consolidates land and sea observations as well as remote sensing. Discussion of the various types of observation equipment is reported in more depth on [17] as the result of TOWS WG Meeting on February 2018 [18].

Tsunami ready is not a mere of readiness response. But, it also includes various aspects of training, practice, and exercise for the community at risk; marking the evacuation path; building temporary evacuation shelters; retrofitting of regulations to accommodate the local vulnerability; mapping tsunami inundation threat; developing curricula to provide local geo-hazards impedance, among others. The ICG/IOTWMS had recently envisioned the tsunami ready program for Indian Ocean members states and held a workshop on Tsunami Evacuation Mapping Planning Program (TEMPP). Each participant from a member state is tasked to practice drawing the inundation map based on agreed tsunami scenario [19].

On the other hand, for hydro-meteorological disaster type, the increasing evidence of the negative impact of the inevitability of climate change manifests in the growing number and upscaling of the intensity of disasters. It is admitted that high-impact weather and climate extremes bring the overwhelming cost for the safety of people, national economies, and other climate-sensitive sectors. Hydro-meteorological extreme events dominate 80% of the world’s natural disasters.

The significant progress of EWS, especially in term of technology, cannot catch up the increasing scale of intensity of disaster, especially hydro-meteorology one. As clearly described in [15], two events have propelled WMO to review the progress achieved. WMO found the missing factor lies in the perceptivity of the potential impact that is caused by the potential hazards. WMO

foresees transforming the way of forecasting through a simpler phrase: "*Shift from informing what the weather will be to what the weather will do*" [16]

The global development of EWS in the hydro-meteorological field is projected through the implementation of a new paradigm of impact-based forecasting and risk-based warning. After the SFDRR 2015, the new paradigm endorses a lot of directive WMO's technical resolutions for the materialization of the standard.

Briefly, at the upstream part, the WMO Integrated Global Observing System (WIGOS) will direct the global standard observing system of the respective member toward 2040 [20], where most of data acquisition is automation and exchange globally and openly. The processing will be seamless of weather and climate forecasting supported through global data production and forecasting system, the reference of which can be reviewed in [21, 22]. The global standard format is foreseen through the development of the so-called Global Multi-hazards Alert System (GMAS) [23].

6 Concluding remarks

An early warning provides information on the occurrence, gives people time to take action before it becomes a disaster; enables local authorities to evacuate people in advance and enables a faster response and preparedness for further action after the disaster hit the location. Therefore, an EWS is very pivotal in improving the performance of DRR.

The global state of development has been reviewed in three periods of times state of its development, namely before IOT04, existing development and global trend.

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