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EUROPEAN UNION

Development of early warning systems suited to combined risk management

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Summary

Abstract

Early warning system suited to combined risk management for the pilot area of Kaštel Kambelovac is presented. Sea flooding risk combined with seismic risk, as the most likely threats in the study area, are selected for the elaboration of early warning systems for combined hazard risk. Early warning system for multi-hazard risk of the area is based on several deliverables: (1) “Combined Risk Management Plan” (5.2.3) which considers combined flood-seismic and flood-seismic-extreme sea waves risks and further visualize the combined risk scenarios; (2) “Development of early warning systems suited to single risk management” (5.1.1); and (3) “Development of warning systems that decide when coastal flood warnings shall be issued” (5.1.5).

1 Introduction

The purpose of PMO-GATE 5.2 Activity “Improved early warning systems for multi-hazard risk” is to elaborate how the information and communication technology (ICT) can be integrated into an early warning system for multi-hazard risk. Herein, the sea flooding risk is combined with seismic risk as the most likely threats in the study area. The simultaneous occurrence of these two risks is not to be excluded thus their consequences on the population, environment, and infrastructure will be multiplied. The first step is to visualize risk scenarios for the combined risks to citizens and authorities involved in disaster management.

The deliverable Combined Risk Management Plan (5.2.3) [1] considers multi-hazard or multi-risk events as following:

- Combined flood-seismic, and
- Flood-seismic-extreme sea waves risks.

Figure 1 illustrates exposure of the pilot area Kaštel Kambelovac to combined risks of sea flooding and earthquakes.

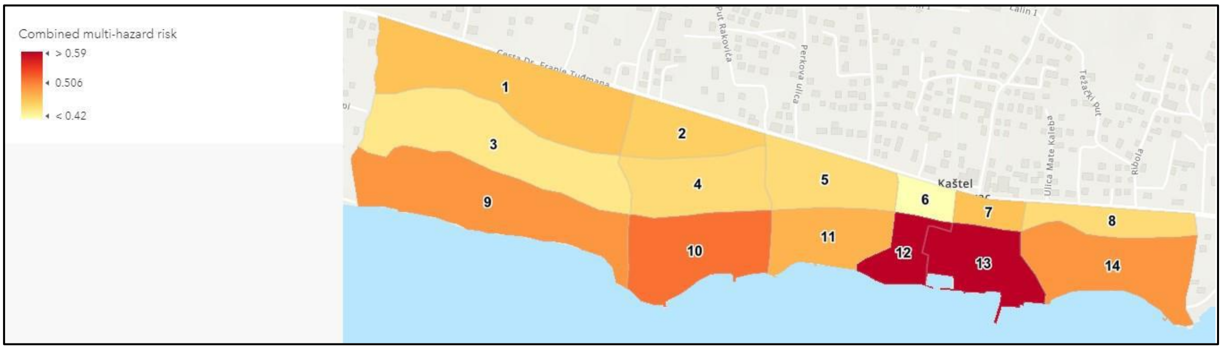

Figure 1. Exposure of the Kaštel Kambelovac pilot location to combined risks [1]

The Activity elaborates early warning systems that deliver timely information about the risks to all stakeholders: relevant authorities, the emergency response community and citizens. The information and communication technology (ICT) tools and systems are considered to improve preparedness and response to sea flooding and seismic actions.

From the early warning systems perspective, two distinctive situations are considered for the pilot area:

1. One or more disastrous event is triggered by another event, and
2. Two or more disastrous events occur independently in the same time period.

United Nation International Strategy for Disaster Reduction (UN ISDR) defines the four elements of an effective early warning system. With the aim to achieve people-centred early warning systems, the system should encompass a risk knowledge; technical monitoring and warning service; communication and dissemination of warnings; and community response capability [2]. Hence, ICT tools should support all the processes constituting early warning system.

From ICT perspective, a basic ICT architecture for the early warning system is a three layered architecture consisting of a Perception layer, a Communication layer, and an Application layer [3]. The perception layer consists of a network of sensors that collect data from the environment. Sensors are equiped with communication devices that send data to a server or application composing the Communication layer. Thus, Communication layer is responsible for reliable data transfer in complex and heterogenaous networks, using different communication technologies (wired, wireless etc). Additionaly, as disasters can cause failure of the communication infrastructure, redundant communicatiom chanells are usually designed and employed. The Application layer provides services of generation and broadcasting eraly warning messages. Algorithms are processing all the collected data from sensors and from other sources such as satellite, weather forecasting data or historical records. The Application layer provides complex risk models, data storage for historical and real time data and user interfaces.

According to the Sendai framework, an efficient disaster management requires a multi-hazard approach and use of ICT technology. Today, widely availabe ICT tools, open standards and various sensors enables developing of multi-hazard warning systems with low costs [4]. For multi-hazard risk, the above explained ICT architecture assembles sensors that perceive parameters of selected hazards, and the Application layer performs risk analysis of combined risk and hence generates adequate early warning messages.

The following chapters describe the elements constituting the early warning systems for the most likely threats in the study area and finally elaborates prospects for building combined early warning system. At the end, a conclusion and a list of references are given.

2 Early warning system for sea flooding due to climate induced sea level rise and extreme sea waves

During a storm, strong wind that pushes the water towards the coastline and low atmospheric pressure that rise sea level together cause sea flooding known as storm surge. Monitoring meteorological and marine conditions is a prerequisite for a prediction of sea flooding due to climate induced sea level rise and extreme sea waves. Together with data describing morphological characteristics of the coastal zone, risk modelling for the hazard risk could be performed and finally, the early warning messages produced and broadcasted.

In the European Union countries, The Floods Directive (2007/60/EC) requires that countries assess flood risk, prepare hazard risk maps including coastal areas. Hence, The Floods Directive implementation contributes to the development of early warning systems. In Croatia, The Croatian Water Authorities are responsible for flood risk assessment [5] and warnings including sea flooding as part of Adriatic Sea basin.

On the European Union level there is a Meteoalarm service [6] that provides meteo alerts of severe weather and corresponding hazard risk including severe coastal events. The colours on the web maps illustrate the severity of the danger. Additional information is available such as time of the hazard event and its intensity. The service is developed for the Network of European Meteorological Services and it integrates weather information collected from National Public Weather Services. The strength of Meteoalrm service is in consistent interpretation and presentation of weather conditions and events for the whole EU territory.

In Croatia, The Meteorological and Hydrological Service (DHMZ) provides Early Warning Systems for severe weather conditions including marine meteorological conditions [7]. The Marine Meteorological Center in Split, an unit of DHMZ, monitors and forecasts marine weather and provides warnings for ships, ports and anchoring sites, nautical activities, marinas etc. As the Croatian coastline is long and mostly uninhabited, there are rare observation stations. Hence, the marine conditions along the coastline are derived by modelling [8].

Accordingly to the guidelines developed for the Adriatic-Ionian region [8], to achieve an effective early warning systems for sea storms it is necessary to have the following:

- The online sensors networks for marine monitoring (tide gauges, wave buoys, wind and pressure sensors, etc.);
- A geodetic network for land height monitoring and definition of local references for sea level monitoring;
- High quality forecasts and particularly forecast of sea levels for citizens and emergency services;
- Definition of combined coastal risks and warning levels; and

- Real time sharing of data with other countries along the coastline.

The same study [8] suggests that stakeholders prefer broadcasting of warning messages via SMS messages and mobile application. This is followed by sending messages via mass communication and traditional media such as websites, social media, radio and TV.

For the pilot area of Kaštel Kambelovac, a digital sea level monitoring system is developed under the name "Waves – seafront monitoring". It also includes location service for the positioning of the user.

The three parts are as follows [9]:

1. Mobile application
2. Google Firebase server component
3. Integration of data from the sensors

Map as the central part of the application contains the following functionalities:

a. Drop down menu where the user has a choice between three languages: Croatian, English and Italian (Figure 2, number 3);

b. Log out button from the application (Figure 2, number 4);

c. Values read from the sensor and total sea height calculated by the algorithm based on tide, speed and wind direction, and atmospheric pressure (Figure 2, number 5);

d. Google maps with coastline mapped respectively to heights, flood risk zones (green - safe; yellow - warning; orange – dangerous; red – flooded; Figure 2, number 6);

e. Zone maps showing the names and photos of coastal zones (Figure 2, number 7);

f. Notification button (Figure 2, number 8).

Figure 2. Components of tsunami early warning system [4]

3 Early warning system for tsunami

A tsunami is a phenomena of large waves resulting from seismic events, volcanic eruptions or underwater landslides while meteotsunami results from severe storms. The waves approaches the coast and by interacting with the sea bottom and shoreline, the waves increase in height and strength and become more destructive.

Tsunami's prediction needs data on seismic activity and event detection, while meteotsunami's prediction needs various meteorological measurements, sea water levels and waves measurements. In addition, hydro-acoustic sensors are used for detecting movements in the sea bottom and video cameras for detecting large waves (Figure 3).

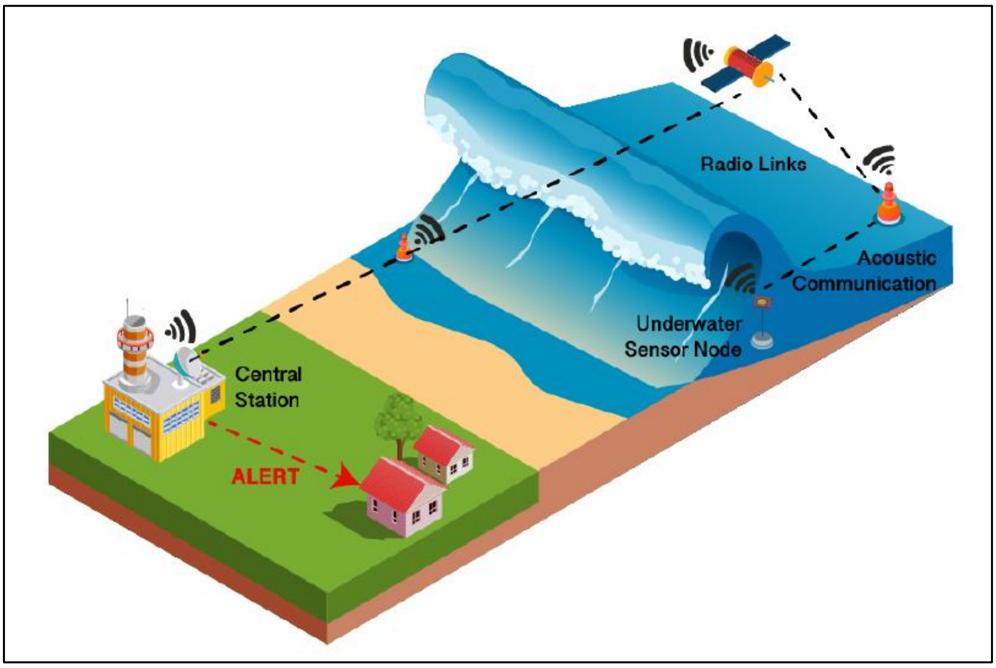

Figure 3. Components of tsunami early warning system [4].

In Europe, a regional Tsunami Warning System for the North East Atlantic, Mediterranean and connected seas region (NEAMTWS) is established. The following components are developed [10]:

- Global Disaster Alert and Coordination System (GDACS) which includes tsunami modelling;
- Tsunami Scenario database;
- Tsunami Analysis Tool;

- Tsunami Alerting Device to quickly display tsunami warning messages;
- Sea Level Database and connected Sea Level Instrumentation network.

The exposure index for meteotsunami for the pilot site Kastel Kambelovac is low as elaborated in the deliverable "Definition of meteotsunami exposure index for the HR test site" (3.2.1). However, the analysis of the meteotsunami events in the past showed that there were 30 meteotsunamis that hit the eastern Adriatic (Figure 4), as elaborated in the deliverable "WebApp for tsunami and meteotsunami effects observed in ITHR coasts" (3.2.3/3.2.4/3.3). Therefore, a brief description of meteotsunami early warning system in Croatia follows.

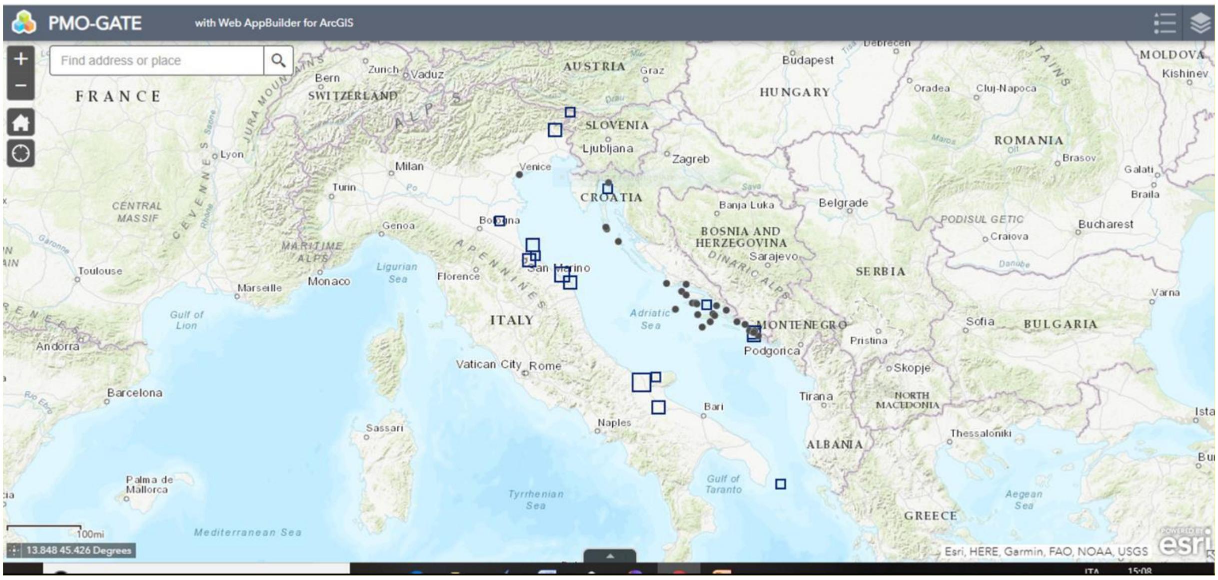

Figure 4. Distribution of localities with meteotsunami (black dots) and tsunamis (blue squares) effects (project deliverable 3.2.3/3.2.4/3.3).

The recently developed Croatian meteotsunami early warning system (CMeEWS) is based on atmospheric measurements from the Croatian Meteorological and Hydrological Service (DHMZ) and additional sensors network consisting of air pressure sensors and tide gauges [11]. Locations of sensors are shown in Figure 5. Meteotsunami modelling uses the deterministic AdriSC modelling suite and the stochastic meteotsunami surrogate model to assess hazard. The results of modelling could trigger warnings and testing of the system has proven the CMeEWS approach [11]. Since November 2019, the CMeEWS is not in operation due to a lack of computing resources needed for model calculation in real time.

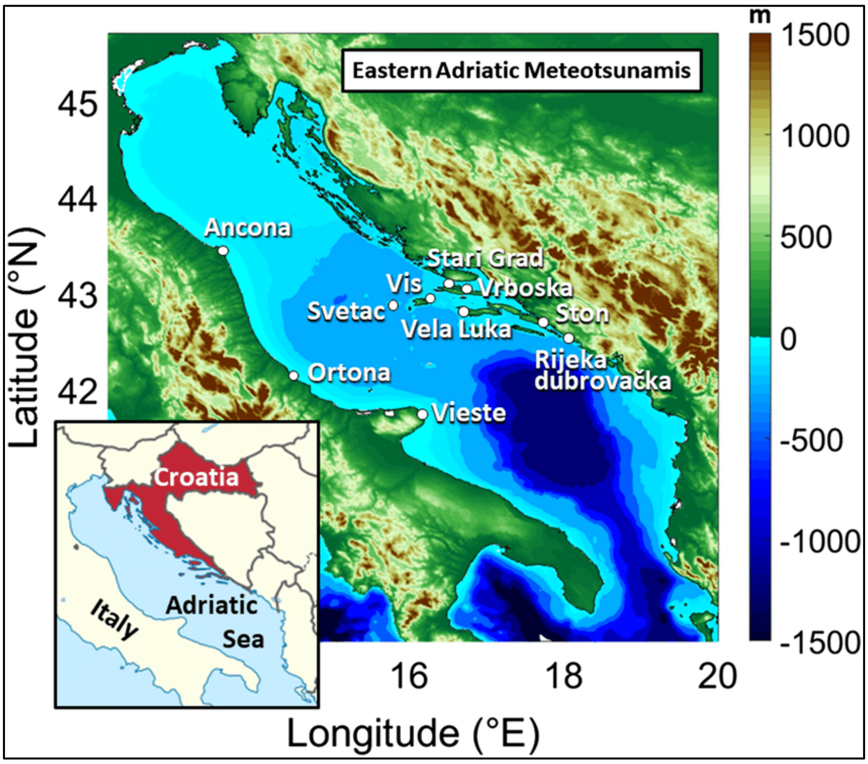

Figure 5. Locations of sensors network in the Adriatic Sea and sensitive harbor locations along the Croatian coast [12]

4 Early warning system for earthquakes

Earthquake early warning system (EEWS) is the least advanced early warning system related to natural disasters. There has been a continuing effort to set up an effective EEWS, firstly by simply measuring seismic activities with relatively dense seismometers network, which issues an alert when ground acceleration exceeded a threshold and nowadays with by detecting non-destructive and faster primary waves before secondary, destructive ones (P and S waves). Unfortunately, the time window between primary and secondary waves is quite narrow and ranges from few seconds for the areas close to the epicentre to like 90 seconds to the more distant spots. Nevertheless, for the earthquake prone areas even a narrow time window may save lives. Another challenging issue is to eliminate ground vibrations caused by other local activities and send false positive alarms.

However, it should be emphasised that EEWS cannot predict an earthquake because it records already occurred ground motions in a more or less proximity to the populated areas and predicts intensity with which the seismic event will reach the area.

Globally, EEW systems are either fully operational or semi-operational. They are deployed in earthquake prone countries like Japan, Mexico, Turkey, Romania, China, Italy, and Taiwan, having various levels of maturity and warning organisations [13].

Japanese EEWS has the most advanced mechanism as it predicts magnitude and warnings are automatically transmitted to mobile phones, television and radio. The system is well integrated across society, which makes it trustworthy. Turkey and Mexico do not predict magnitude but have alarm systems using public sirens. In Mexico City, a ubiquitous network of sirens is being activated after detection of a significant shaking so the residents have time to find safe place before shaking arrives. [14]

EEWS in USA is rather challenging, as earthquake mechanism is different. Italy and Romania have regional approach using dense sensors' networks.

Moreover, experience of the population is crucial, as, at the beginning, hearing alarm may be confusing. Still, there are also false alarms and errors [15].

On 22 April 2022, an earthquake occurred with the epicentre in Bosnia and Herzegovina, which was felt in Kaštela region, as well. Many people surprisingly got the message on their mobile phones that an earthquake is about to occur with the estimated magnitude. This was the first time that Google algorithm worked in Croatia. Using the paradigm, a person with mobile phone is a sensor; Google has been creating a worldwide, android phone-powered earthquake alert system as the accelerometers are built in mobile phones [16]. This is the follow-up of the Google's collaboration with the United States Geological Survey and the California Office of Emergency Services, primarily for California to send earthquake alerts generated by the existing Shake Alert system to Android users. The Shake Alert system uses data from the deployed sensor's network. The next step was to use a network of mobile phones as sensors together with algorithms on big data and to expand this solution to other countries, primarily where the sensors' networks do not exist.

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Nevertheless, this solution could be a good starting point for Civil Protection authorities in Kaštela to start creating early warning system. However, this solution is only an added value to a network of sensors and comprehensive civil protection earthquake alerting system.

The pilot site Kastel Kambelovac is rather prone to seismic hazard as elaborated in the deliverable "Seismic risk management plan" (5.1.2). Since EEWS for the pilot site of Kastel Kambelovac has not been put in place yet, herein, recommendations for the future development of such system are given. The Figure 6 shows the very basic scheme of the EEWS for the pilot area.

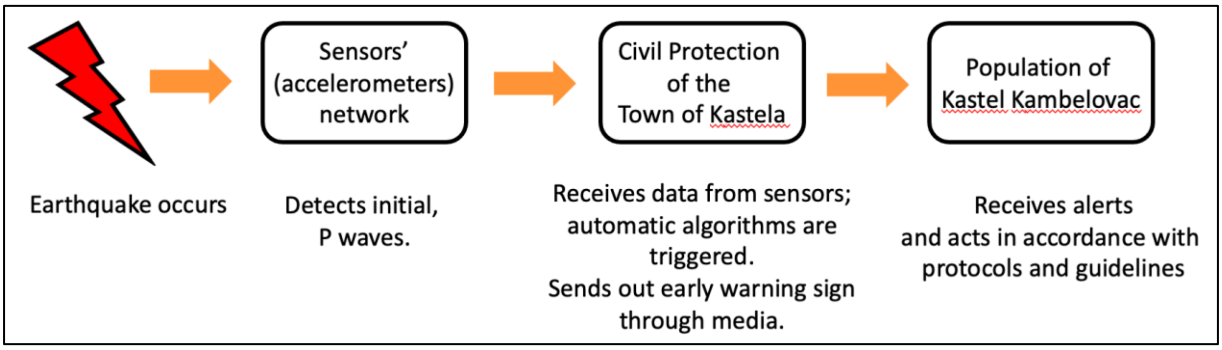

Figure 6. A basic scheme of the EWWS for Kastel Kambelovac

Based on the worldwide experience of establishment of EEW the recommendations for the EEWS are given. For the pilot area, it seems that the regional approach like in Italy and Romania could be the practical one, as the national or regional EEWS are not developed yet. However, this decision depends on the future developments of EEWS in Croatia and future decisions to be taken at national level. The recommendations are the following:

- Conduct thorough analysis and install a dense earthquake sensors' (accelerometers) network in a wider region of the pilot area.
- Evaluation of the algorithms that use information from sensors to calculate P and S waves arrivals and predict the magnitude of an earthquake in the pilot area.
- Calculation of time window including delays for automatic real-time data analysis. Analysis of the proximity of potential epicentres to the pilot sites, the smaller the distance the lesser the time window and efficiency of the EEWS.
- Setting up the magnitude threshold when to send out the warning sign, considering the vulnerability and risk assessment of the pilot area.
- Define the vulnerability of buildings and critical infrastructure, which is done within the PMO-GATE project. Namely, *Seismic vulnerability index for buildings* $V_{s(b)}$ is calculated for the pilot area. The particular attention should be paid to the critical infrastructure as defined in the

"Seismic risk management plan" (5.1.2), Table 8: Water and municipal infrastructure, energy infrastructure, transport infrastructure, telecommunication infrastructure.

- Integration of EEWS in the civil protection system of Kaštel Kambelovac, particularly in the Goal 3 of the earthquake risk management measures [17]: Involving the local community in activities in order to promote the importance of risk prevention and disaster resilience, which appears within the measure 3.1 Raising awareness of the general public with regards to seismic risks, behaviour and protection protocols in the event of an earthquake, as well as disaster resilience.
- Integration of Kastel Kambelovac EEWS into county/national system.
- Finding the most efficient way of alert systems. Mobile phone application is very efficient nowadays, but still having more general warning system like using TV, radio or even public sirens system may be even more efficient for elderly people and tourists. However, this decision should be balanced with potential negative effects of false alarms.
- Setting up the protocols and guidelines for the population after EEW sign is launched. This is particularly important for the critical infrastructure. Establishment of meeting points. Conducting regular drills for the population. As there are no high, multy-floor buildings in Kastel Kambelovac the evacuation could be very efficient in a short time window between the alert and the arrival of a ground motion.
- As there is no hundred percent accuracy of EEW systems and false alarms happen relatively frequently making population familiar with such situations is crucial. The study of the effects of false alarms to economy as expert analysis is also necessary, especially for the tourism in the pilot area. The calculation of costs of false alarm may be very useful.
- Based on risk assessment of the pilot area raising population awareness about their vulnerability through public campaigns.
- Explore how to incorporate existing Google early warning system for Android mobile phone users into the solution.

5 Combined early warning system

The deliverables Web Map with Combined Risks Exposure for HR Pilot Site (4.1.2) and Combined Risk Management Plan (5.2.3) consider multi-hazard or multi-risk events as following:

- Combined flood-seismic, and
- Flood-seismic-extreme sea waves risks.

From the early warning systems perspective, two distinctive situations are considered:

- One or more disastrous event is triggered by another event;
- Two or more disastrous events occur independently in the same time period.

Bearing in mind recognised natural hazards that may happen in the pilot area, the first one relates to the earthquake which occurs undersea and may have significant ground motion on the land generating at the same time a kind of tsunami manifesting as an extreme waive or rapid sea level rise (flood). Having an alert for both events, population is instructed to leave their homes because of the earthquake and move as far as possible from the coastal area, which may be problematic if the seismic event destroys roads or rubbles block roads.

In order to be effective in terms of earthquake early warning, such solutions demand seismic sensors with adequate submarine communication towards land. These systems are very costly and considering extremely small odds of such situation in the pilot area it is not cost-effective to plan such systems. According to [18], such systems with dedicated cabled ocean bottom observatories have been installed only in Japan and Cascadia. Otherwise, systems use sensors' network deployed on the land which, in the pilot case, will not be able to assure adequate time window between the time early warning alert is sent out and occurrence of the ground motion in the area.

Regarding tsunami warning alerts, one of the solutions is to deploy a series of detection buoys receiving bottom pressure data from the recorders and equipped with GPS communication systems. They have to be deployed in the sea area with expected earthquake events. Figure 7 shows a scheme of Deep-ocean Assessment and Reporting of Tsunamis (DART) buoy firstly installed by the US National Oceanic and Atmospheric Administration (NOAA) in 2001 [18].

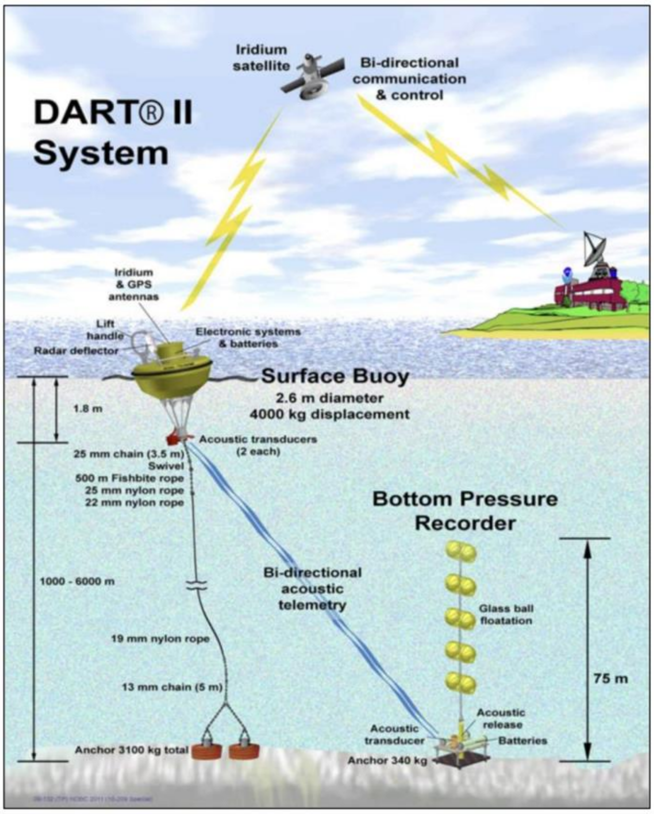

Figure 7. DART II System Overview [17]

In case of fully operational system an early warning alert can be sent as a sequence of warning, firstly for an earthquake event and then for estimation of tsunami effect. As the whole system is costly and probability of such combined hazard event is extremely low in the pilot area it is not realistic that the system will be deployed.

The second situation may happen, for example, if during the flooding induced by either evident danger or actual situation of extreme sea waves or atmospheric pressure an earthquake hits the pilot area. In such case, staying at home during the flooding is not the safest place to be for the earthquake event. Herein, knowing that flooding is expected or is already occurring an additional warning with the alert message for an earthquake is triggered, telling population to keep away from the coastal line while evacuating form the earthquake hazard, or to stay at homes using predefined safe spots in their homes (like tables and structural features).

6 Conclusion

Sea flooding risk combined with seismic risk, as the most likely threats in the study area, are selected for the elaboration of early warning systems for combined hazard risk. Therefore, the deliverable "Combined Risk Management Plan" (5.2.3) [1] considers combined flood-seismic and flood-seismic-extreme sea waves risks and further visualize the combined risk scenarios.

Today, widely available ICT tools, open standards and various sensors enables development of warning systems with low cost. For the pilot area of Kaštel Kambelovac, a digital sea level monitoring system is developed under the name "Waves – seafront monitoring" covering sea flooding caused by wind and atmospheric pressure. To extend such single risk early warning system to combined risk systems, other hazards should be monitored and predicted, and then the combined risks have to be calculated.

There are still lot of science and data gaps to achieve this, as explained in this report. As an early warning is a key factor in disaster risk reduction, there are local, national and regional efforts in building such systems. According to [19], the four key elements of an early warning system are the following:

- Disaster risk knowledge based on the systematic collection of data and disaster risk assessments;
- Detection, monitoring, analysis and forecasting of the hazards and possible consequences;
- Dissemination and communication, by an official source, of authoritative, timely, accurate and actionable warnings and associated information on likelihood and impact; and
- Preparedness at all levels to respond to the warnings received.

Combined multi-hazard approach is recognized as critical to the development of early warning systems, together with governance and involvement of local communities. The PMO-GATE project has demonstrated the both.

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