# Development of Multi-Hazard Early Warning System in Indonesia

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***Abstract:*** *This paper discusses the results of Multi-hazard Early Warning System (MHEWS) development that combine weather prediction from Weather Research and Forecasting (WRF) and hydrometeorology hazard index from National Disaster Management Authority (BNPB), Indonesia. Until now, the predicted hazards in MHEWS that has been produced are flood, landslide, and extreme weather. These indices were obtained by using overlay approach and resample methods so that the data have 100 m spatial resolution. All potential hazard indices are classified into 4 status categories. These categories are "No alert", "Advisory", "Watch", and "Warning". Flood potential was produced by using overlay methods between 3-hours interval rainfall prediction and flood index. Landslide potential was produced from overlay method between rainfall prediction and landslide index. Extreme weather potentials are divided into 3 categories which are heavy rain, strong winds, and high wave. The whole of prediction is dynamic following weather prediction in 3-hourly interval. Then, this hazard prediction results will provide "warning" sign especially for the alert status "emergency". This sign will be set up into notification system for making user easier to identify the most dangerous hydrometeorology hazard event.*

***Keywords:*** *multi-hazard early warning system (MHEWS), warning, hydrometeorology, weather prediction, high resolution, flood, landslide, extreme weather*

## 1. INTRODUCTION

Several early warning systems have been developed in Indonesia. Indonesia Agency of Meteorology, Climatology, and Geophysics (BMKG) developed early warning systems for extreme weather that could be accessed at http://web.meteo.bmkg.go.id/. People could get information about prediction of thunderstorms, strong wind, heavy rain and high by accessing the web. The prediction is daily updated for weather condition in 3 days ahead for Indonesia coverage.

Beside the systems above, there is an early warning system called as a Satellite Disaster Early Warning System (SADEWA) developed by Indonesian National Institute of Aeronautics and Space (LAPAN) for Indonesia coverage as well. However, the SADEWA only provides the information on weather prediction and not yet showing hazard prediction. The weather prediction is provided in 0.25° grid spatial resolution (Purwalaksana et al., 2015). In micro scale, flood early warning system was already well developed, especially in Jakarta region. Since Jakarta is a flood prone area, it has been built a Jakarta Flood Early Warning System (J-FEWS) as stated by Ginting, et al. (2013). Those systems have become operational flood forecasting and warning system based on The Delft-FEWS (Hatmoko et al, 2015).

As an official institution that managing hazard, National Disaster Management Authority (BNPB) has developed inaRISK (hazard risk index monitoring in Indonesia) that can be accessed at www.inarisk.bnpb.go.id. The collection of hazard indices has been compiled in a book, which titled Indonesia Disaster Risk (National Disaster Management Authority, 2016). Flood hazard index on that system was obtained from overlay method adopted from Manfreda, et al. (2009). Using this method, the flood-prone areas were created by modifying the DEM raster data into topography index and compared to flood threshold value. The flood threshold values were obtained from major river network. The limit of this flood hazard index is the absence of rainfall factors that is usually a major trigger for floods event.

This paper discusses the results of inaRISK development to be more dynamic after combined with weather prediction with 3-hourly time step for 3 days ahead. The result of this development was called as Multi-Hazard Early Warning System (MHEWS) in Indonesia which could be accessed at http://mhews.bnpb.go.id.

## 2. METHODS

The prediction of hydro-meteorological hazard potential is made to be more dynamic by overlaying hazard index of inaRISK and weather prediction for Indonesia coverage. Figure 1 shows the flow of MHEWS development that combining two types of data which are hazard index inaRISK and the indexed weather prediction index. This scheme shows the main informative sources, the components, and the results of GIS data processing in Server PC. Using GIS technology, the MHEWS could be developed by integrating common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits that is offered by maps (Burrough, 1990). The MHEWS is processed in GIS so that all information can be linked and processed simultaneously. A syntactical expression of the changes is induced in the system by variation of a hazard index.

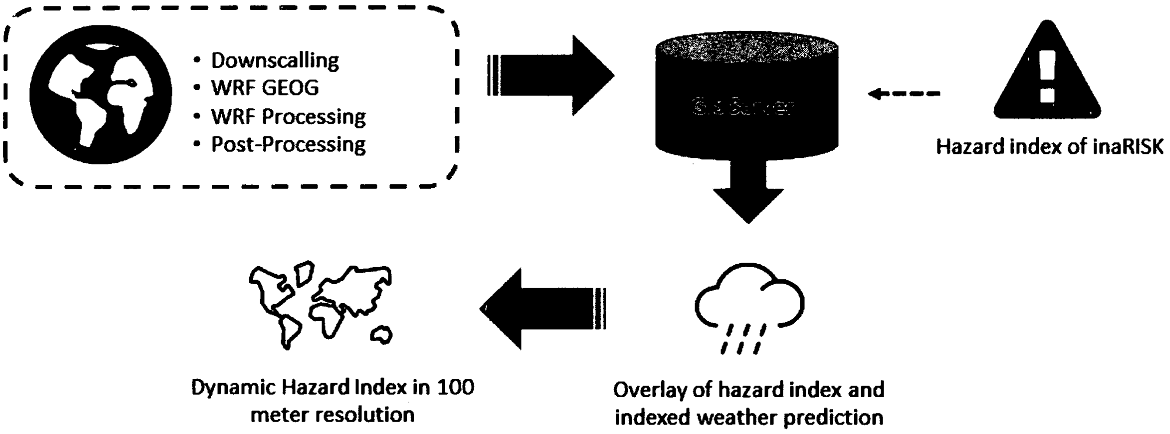


Figure 1 Flow of MHEWS processing

Hazard index MHEWS input was obtained from inaRISK consisting of flood, landslide, and extreme weather map. Flood hazard refers to flood-prone areas data and inundation depth based on PERKA No. 2 BNPB/2012. DEM raster data was developed into flood-prone areas through topography index modification by the equation:

$$TI_m = \log\frac{a_d^n}{\tan(\beta)} \qquad (1)$$

Where $TI_m$ is topography index modification, ad is flow area per length contour unit (or value of the accumulated flow based on DEM data analysis; values depending on DEM resolution), tan (β) is the slope (based on DEM data analysis), and n is the exponential value, the value of n is calculated by formula n = 0.016x0.46, where x is DEM resolution. Flood-prone areas were identified using a threshold value (T). If the topography index value is greater than threshold value (Tim> T), the area will be categorized into flood-prone area with T = 10.89n + 2282. Furthermore, the flood hazard index is estimated by the slope and distance from the river at the flood-prone areas with fuzzy method.

MHEWS second type of hazard is landslide hazard. Landslide hazard zone classification was based on the vulnerability of ground motion issued by Centre of Volcanology and Geological Hazard Mitigation (PVMBG) and corrected with slope above 15%. Landslide hazard index was obtained by danger area delineation after performing overlay between landslide vulnerability zone and slope analysis.

Furthermore, extreme weather consists of strong winds, heavy rainfall, and extreme ocean waves. Strong winds and heavy rainfall was obtained from the scoring method of its constituent which are openness Land, slopes, and annual rainfall. The constituent parameter which composes extreme wave consists of wave height, ocean currents, typology of coast, vegetation cover, and the shape of coastline.

## 2.1. Downscaling WRF Output into 5 Km

The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation system which was designed for both research and operational applications (Scarmarock et al., 2008). However, to make it operational, WRF output should be downscaled to be higher resolution. In this research, downscaling process was performed to increase the resolution of weather prediction to be 5 km. WRF output with 5 km spatial resolution is nested in 3 domains.

To support the hazard index resolution, the weather prediction has been generated in layers at 100 meter resolutions using resample method (Usery, et al., 2004). With resample method, resolution of two data (inaRISK index and the indexed weather prediction) will be same. This is because inaRISK maps provide in 100 m x 100 m resolution but weather prediction only has 5 km resolution. Result of this resample is weather prediction maps in raster form which have 100 m resolution.

## 2.2. Creating Hazard Index Prediction

Map of hazard index prediction was generated by overlaying weather prediction map with inaRISK map. After that, the overlay map will be generated to be new index representing prediction of the occurrences of hazards in Indonesia. The digital hazard index and weather layers were overlaid and integrated in GIS media by raster calculator functions (Nasrollahi, et al., 2017), then zoning of region was done in 4 classes, including “No alert”, “Advisory”, “Watch”, and “Warning”. The classes were applied to flood, landslide, and extreme weather.

Flood and landslide hazard index derived from combination of calculation and weighting of rainfall and in a RISK index. Flood and landslide hazard indices obtained by the following formula.

$$IK = 0{,}2 * IR * 20 + 0{,}8 * R \qquad (2)$$

Where:
IK: hazard index that the value will be defined and used as the value of hazard warning
IR: inaRISK index
R: the amount of rainfall

Furthermore, hazard index (IK) is classified into 4 groups of emergency hazard in Table 1 below.

Table 1 Hazard Indices

| IK Value (Hazard Index) | Status | Color |
|---|---|---|
| **<8** | No Alert | Green |
| **8-11** | Advisory | Yellow |
| **11-15** | Watch | Orange |
| **>15** | Warning | Red |

Illustration:
For example, in an area having index for flood is 0.2 with rainfall over a time step reaches 15 mm, then hazard index values were as follows.
IK = 0.2 * 0.2 * 20 + 0.8 * 15 = 12.8 (3)
Based on the table of IK value, the value of 12.8 into the group and will alert warning orange in hazard warning map.

For the category of extreme weather, the value used is the value of the weather and maritime prediction issued by the system henceforth it was grouped into several categories.

**Heavy rain**
In heavy rain, rainfall prediction is grouped into 4 hazard groups as follows (Table 2).

Table 2 Index and the status of heavy rain

| Rainfall | Status | Color |
|---|---|---|
| < 5 mm | No Alert | Green |
| 5-10 mm | Advisory | Yellow |
| 10-20 mm | Watch | Orange |
| > 20 mm | Warning | Red |

For example, if the rainfall in an area is 18 mm in one step a time then the area at that time alert status is extreme weather and heavy rain. It will be orange on the map of extreme weather warnings showing heavy rain.

**Strong winds**
In high winds, the wind predictions of hazard are grouped into 4 groups as shown in Table 3 below.

Table 3 Index and the status of strong winds

| Rainfall | Status | Color |
|---|---|---|
| < 3 m/s | No Alert | Green |
| 3-5 m/s | Advisory | Yellow |
| 5-8 m/s | Watch | Orange |
| > 8 m/s | Warning | Red |

For example, if the wind speed in an area is 9 m / s in one step a time then the area at that time alert status extreme weather and strong winds. It will be colored red on the on the map of extreme weather.

**High wave**
At high tide, rainfall prediction of hazard is grouped into 4 groups as shown in Table 4 below.

**Table 4 Index and the status of high wave**

| Rainfall | Status | Color |
|---|---|---|
| <0.50 m | No Alert | Green |
| 0.50-1.25 m | Advisory | Yellow |
| 1.25-1.50 m | Watch | Orange |
| >1.50 | Warning | Red |

For example, if the wave height in an area is 18 mm in one step a time then the area at that time alert status shows extreme weather and heavy rain and it will be orange in extreme weather warning map.

## 3. RESULTS

Map of high-resolution weather prediction is the most important factor in the hazard prediction. This is due to the disastrous weather, especially rainfall, often be the biggest trigger of the hydro-meteorological hazard. In MHEWS, weather predictions used a high resolution and accuracy weather prediction. The weather forecast has a spatial resolution of 5 km with a long prediction three days ahead and 3-hourly temporal resolution.

In the first development stage, weather prediction plot of MHEWS using static images based on the grads output. However, on the development now, MHEWS weather prediction is made more dynamic by adding a form of wind animation as json format in web. This format allows the user to see displacement wind direction dynamically (Figure 2).

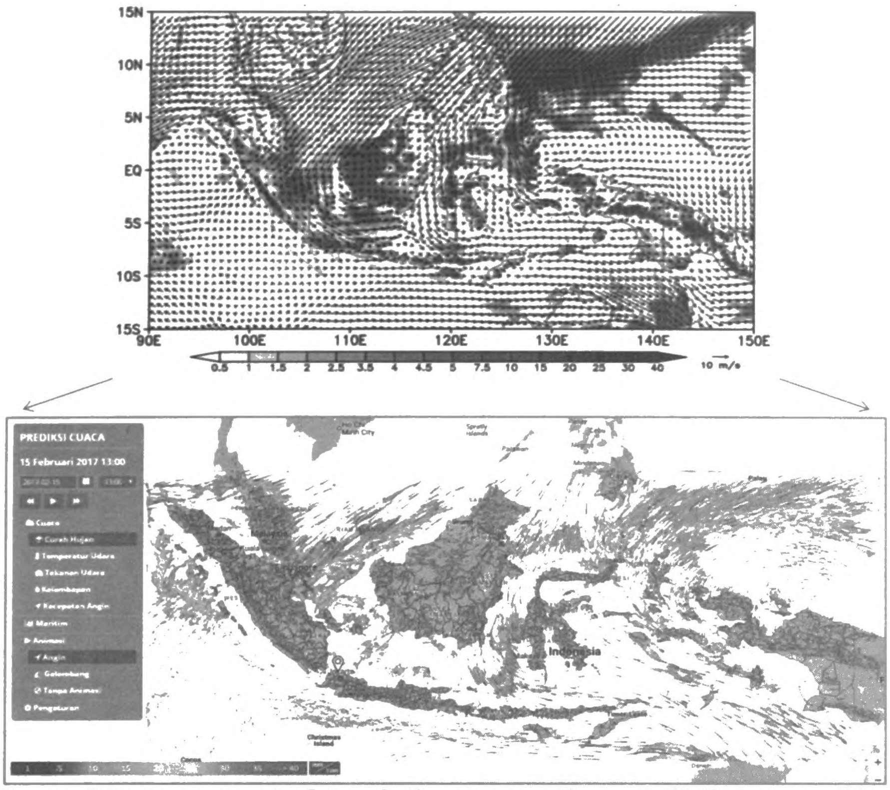


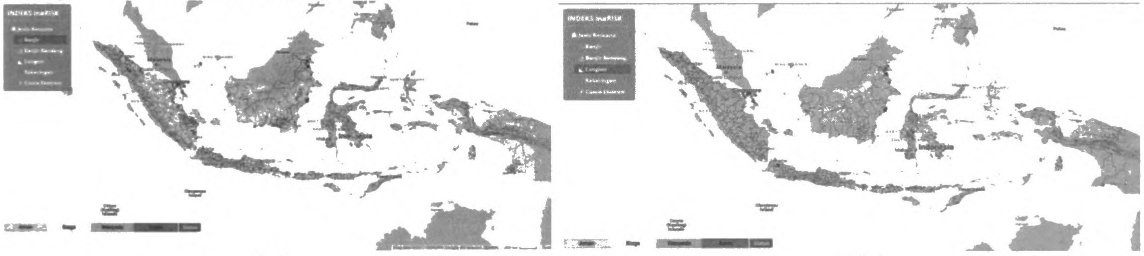
**Figure 2 Improvement of resolution on weather prediction up to 5 km**

In the process described previously, there is a need to do the overlay between the hazard index inaRISK and dynamic weather prediction map to produce an index prediction of hazard for 3 days ahead. BNPB has made hazard index for floods, landslides, and extreme weather events as shown in Figure 3. The green color indicates areas with "no alert", yellow means "advisory", orange means "watch" and red means "warning". This index is established based on the following classification.

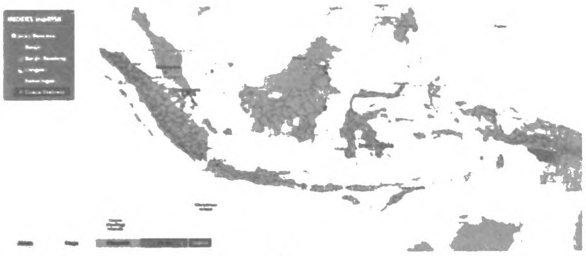
**Table 5 Index and the status of inaRISK hazard vulnerability**

| Index | Status | Color |
|---|---|---|
| 0-0,25 | No Alert | Green |
| 0,25-0,5 | Advisory | Yellow |
| 0,5-0,75 | Watch | Orange |
| 0,75-1 | Warning | Red |

This means that if an area has a hazard landslide index of 0.3, then the area will be colored yellow on the map index prediction of landslides.



(a) (b)

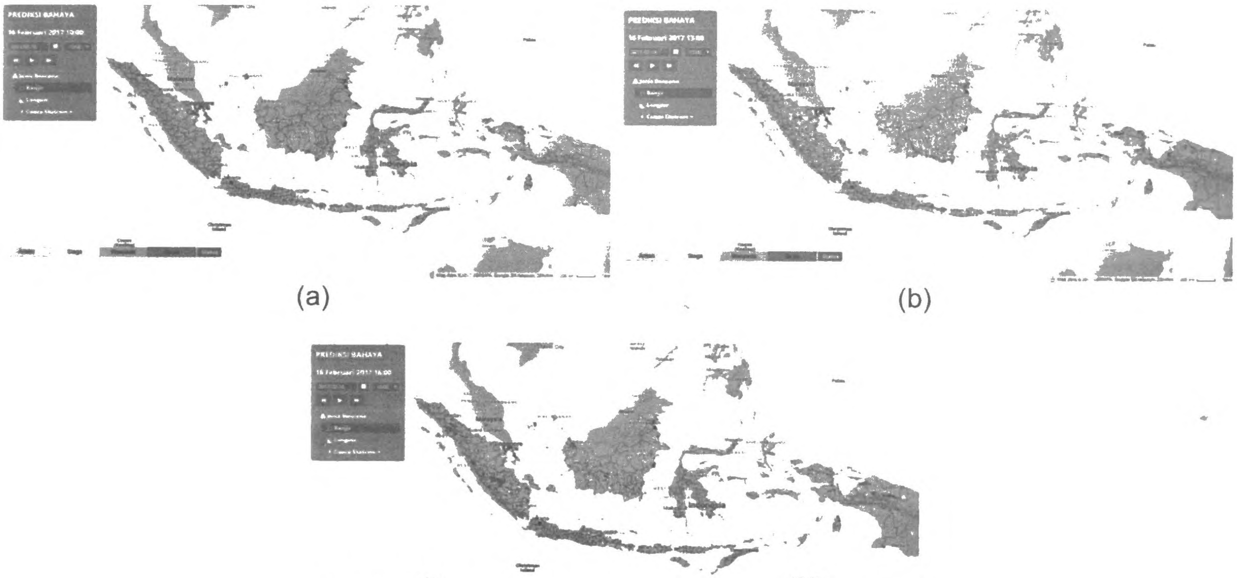


(c)

**Figure 3 Hazard index from inaRISK: (a) flood, (b) landslide, (c) extreme weather**

Furthermore, the result was overlaid with weather predictions along inaRISK hazard prediction. The results of the maps overlay generate new index that represents the potential hazard prediction of the hazard in Indonesia so that mitigation can be done quickly and accurately. Map overlay between inaRISK and weather prediction was done in attempt to form indices hazard that will be displayed in decision support system (DSS) on the website. It will be a hazard index or decision whether an area at a predetermined time, including "no alert", "advisory", "watch", or "warning". Both the hazard index and the inaRISK index that has been made with some existing methods will always be displayed to constantly monitor the results and validated with field data.

Figure 3 lists examples of flood hazard prediction in 3 local times. In Figure 3a shows predictions of hazard at 15 February 2017 at 10.00. This image showing which areas on the red or the warning status of flooding, orange or the watch status, yellow or advisory status, and green areas or no alert from floods. In the figure 3b contains information regarding the status of flooding but with different local time. Figure 3a shows it at 10.00, Figure 3b is at 13.00, and Figure 3c is at 16.00. It could be seen that the changes will go on over time to follow the variation of the predicted weather.



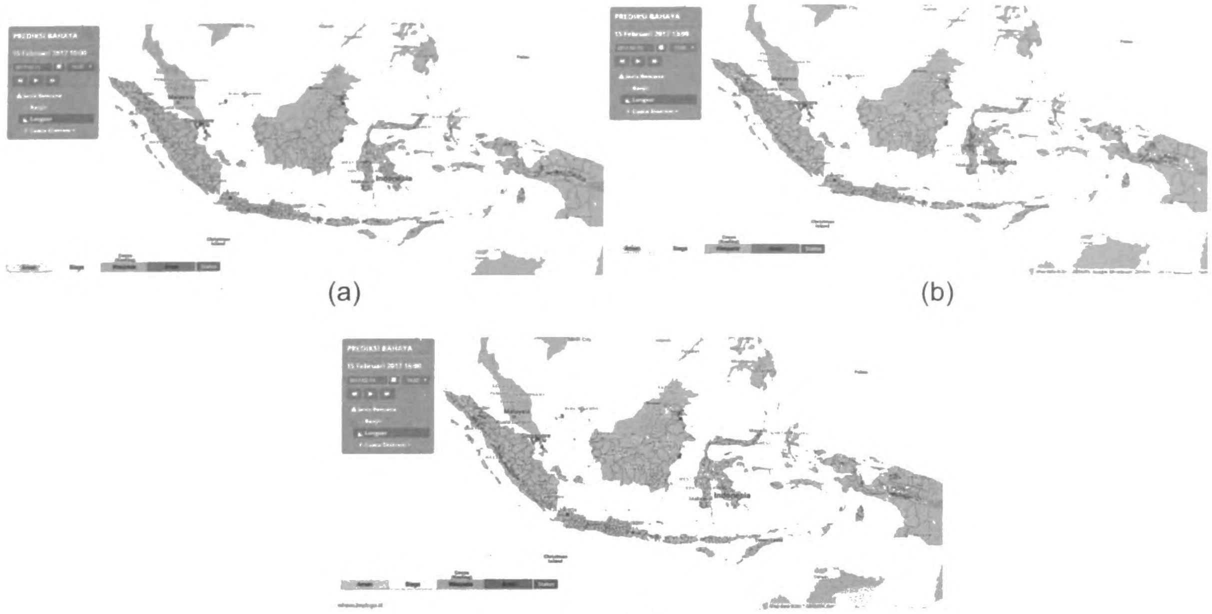
(a)

(b)

(c)

**Figure 4 Prediction of flood hazard index on 15 February 2017: (a) at 10LT, (b) at 13LT, (c) at 16LT**

Figure 4 shows examples of landslide hazard prediction in 3 local times. Figure 4a shows predictions of hazard at 15 February 2017 at 10.00 LT. This image describes the hazard index made from overlay between weather prediction and landslide index. Figure 4b contains information regarding the status of flooding but with different local time. Figure 4a is at 10.00, Figure 4b is at 13.00, and Figure 4c is at 16.00.

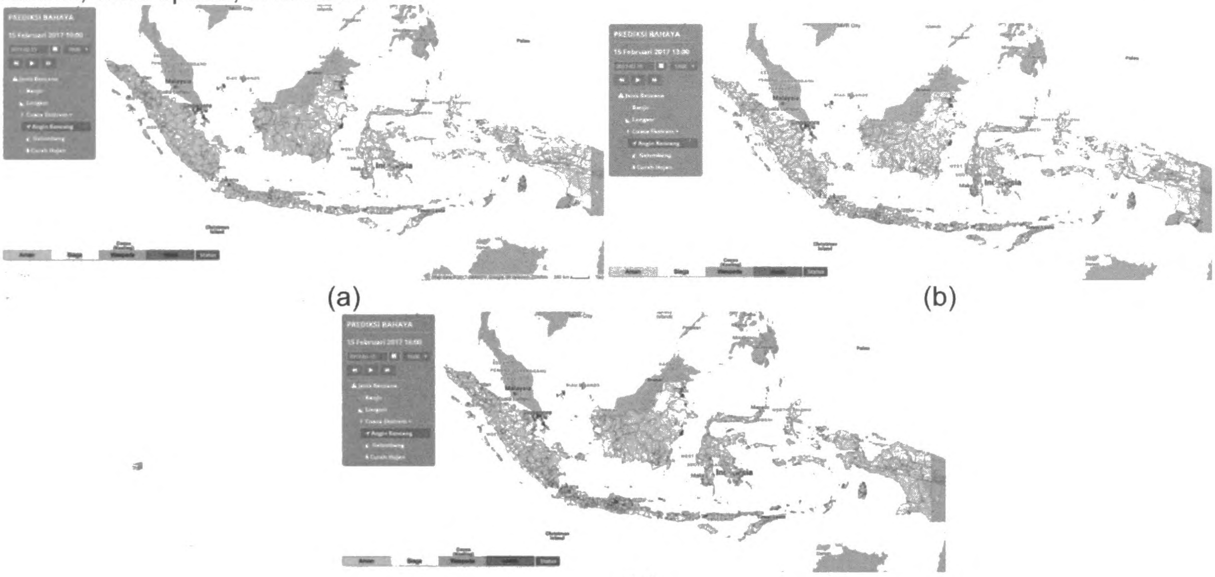


(a) (b)

(c)

**Figure 5 Prediction of landslide hazard index on 15 February 2017: (a) at 10LT, (b) at 13LT, (c) at 16LT**

Figure 5 shows the hazard prediction about extreme rainfall at 3 different times. Figure 5a shows which area at 15 February 2017 10.00 which area categorized as warning to heavy rainfall (red in maps), watch to heavy rainfall (orange in maps), advisory to heavy rainfall (yellow in maps), and no alert to heavy rainfall (green in maps). Figure 5b shows the same figure as 5a but different local time, in 13.00 and 5c at 16.00. The extreme weather index obtained from determination of the weather parameter prediction in rainfall, wind speed, and wave.



(a) (b)

(c)

**Figure 6 Prediction of extreme weather hazard index on 15 February 2017: (a) at 10LT, (b) at 13LT, (c) at 16LT**

The simulation results in hazard prediction to be made in DSS in form of a website are aimed to facilitate the user to read the results of hazard prediction and facilitate in decision-making for mitigation option. At this website, there is also a map that contains a warning status "watch" for a hazard in Indonesia. Visualization of DSS in the website can be shown at Figure 6.

Figure 7 Landslide warning on 15 February 2017 at 10LT

Map loads simulation warning "alert" that allows users to find any hazard that comes into the zone. In this map, there is the option to overlaying with weather maps, for example rainfall or wind speed. In addition, there is an option to download the excel file which contains information on hazard alert in all regions in Indonesia. Selection of this website also contains a link to download an early warning from BMKG.

In the future, these hazard prediction methods will continue to be developed to improve the quality of MHEWS. Therefore, the development of such an increase in the accuracy of the prediction, the development of web sites, and to validate the results of the hazard will always be done to increase the value of the benefits of MHEWS.

## 4. CONCLUSIONS

Society requires hydro-meteorological hazard early warning information to follow weather patterns ahead. This research has produced the information needed by the community as they have built predictive hydro-meteorological hazards in intervals of 3 hours to 3 days ahead which have 5 km spatial resolution. This information can be accessed at MHEWS.bnpb.go.id. This information then be made in DSS in form of a website that inform the user which area that “warning” to hazard. DSS will be the most important information to be user-friendly for society.

## 5. ACKNOWLEDGEMENT

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# Keynote Address

## Investigations on Mechanical Behaviour of Joint Connection in Steel-Concrete Hybrid Structures

by

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Earning his doctoral degree from The University of Tokyo, he joined with the Department of Civil & Environmental Engineering in Saitama University where he currently serves as an Associate Professor. His areas of expertise include Steel-Concrete Hybrid Structures, Seismic Design and soil-structure interaction problems. Moreover, he is an active member of the Japan Society of Civil Engineers (JSCE) where he has extended is service to numbers of technical committees.