Majalaya Flood Early Warning System: A Community Based Approach

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Abstract. Majalaya, a small city to the south-east of Bandung, was hit by flood almost every year. From January to June 2016, up to 5 severe floods and 4 moderate floods have hit this city. Although it usually not last for long, but the flood stream could be very rapid, thus have a high potential to bring damage to the city. Starting from 2012, ITB through Weather and Climate Prediction Laboratory (WCPL) has support Garda Caah (flood watcher society in Majalaya) with weather prediction system. In the late 2015, ITB also enhancing Garda Caah observation system by installing several Automatic Weather Station (AWS) and Automatic Water Level Recorder (AWLR) throughout Majalaya upstream area. The instruments itself was supported by a re-insurance company MAIPARK and some was built in house by WCPL. The collaboration between ITB, Garda Caah, and Majalaya citizens has been proved to be mutually beneficial. Garda Caah could get more accurate and faster observation and enhanced knowledge, thus could provide a better flood warning for Majalaya citizens. On the other hand, ITB could get data from observation network, with more efficient way to maintain observation instruments as it done by Garda Caah and other Majalaya citizens.

Keywords: Majalaya, flood, Early Warning System, community based, weather monitoring, weather prediction

1. Introduction
Majalaya is a small city located to the south east of Bandung (Figure 1). Majalaya also the name of the district, which is part of Bandung Regency, West Java. The city was famous for their textile industries which propel its economy since 1960ies. Beside textile industry, farming and other agriculture activity also plays important role in Majalaya’s economy [1-2].

Majalaya also among the cities that crossed by Citarum River, the longest and largest river in West Java. The Citarum River is spanning from Gunung Wayang in the Kertasari area, to Muara Gembong in Bekasi area, passing through three reservoirs, namely Saguling, Cirata and Jatiluhur [3]. The city itself was part of the upper Citarum watershed, extending from Situ Cisanti in the Kertasari area to the first reservoir, Waduk Saguling. Majalaya is situated in the first 30 km of this upper Citarum watershed with the main river path is passing Kertasari, Pacet and then Majalaya (see Figure 1). In this part of Citarum, many tributaries also exist and contribute to Citarum River just before Majalaya. In case of heavy rain, these situations often cause the river to have excessive discharge, thus flooding the
city. This condition was getting worse by excessive ground water extraction in Majalaya which might causing land subsidence [4] and landuse change in the upstream area which reduce soil ability to hold rainfall [5].

Figure 1. Map of Upper Citarum Watershed with Majalaya area marked with red circle. Purple triangle, brown hexagon, and green square mark the position of AWLR, AWS and ARG, respectively. Black star indicate the edges of Upper Citarum. Basemap, and river and tributaries database was acquired from ArcGIS™ map viewer.

Floods occur almost every year in Majalaya. Based on record by a small group of Majalayan volunteer, it was happening annually since 2008 (Figure 2). Flood also occurs several times in one year. The minimum number of flood occurrence was 6 events (on 2012), and the maximum number of flood occurrence was 20 events (on 2008). However, from January until mid-June 2016, there have been 17 flood occurrences in Majalaya, and this number night still increase until the end of the year as the wet season is yet to come. These numbers indicate that citizen of Majalaya were constantly threatened by floods from Citarum River.

Floods in Majalaya usually happen in relatively short time. The flood water also rise rapidly with quite fast stream, thus it could be categorized as flash flood. When flood happen, some of Majalaya’s main roads were inaccessible, paralyzing the transportation. Most of textile factories, especially those located near the riverbanks also halt their operation. Government and private offices, banks, shops, and other activities were also interrupted by the flood (see Figure 3). Although casualties were minimum, but many citizens lost their goods and belonging, especially when the floods happen without warning.
Figure 2. Annual number of flood occurrence in Majalaya as recoded by Garda Caah. Data on 2014 and 2015 were lost during a flood event in 2015.

To minimize the floods impact, since 2008, several Majalaya citizens took the initiatives to form a flood watcher group, named Garda Caah. Their main activities were manually monitoring rainfall and water level in the upstream area, and issue a warning when the condition was in favor for floods to happen. Their warnings were quite effective to reduce the impact of floods by giving Majalaya’s citizen enough time to prepare for the incoming flood. However, because they do the monitoring manually, sometimes floods happen without any warning issued. Nevertheless, with very limited tools and knowledge, they managed to create a network of observers, a communication system, and flood warning network by cooperating with other groups and societies.

Although Garda Caah’s flood early warning system was quite succeeding, their limited time to do monitoring has limiting the availability of the warning system. An improvement to the system, especially on the monitoring system, is necessary to make a better flood early warning system (FEWS), thus increasing Majalaya’s citizen preparedness against floods.

Figure 3. Photographs of Majalaya flood on 28-29 March 2016 (a) and on 23 May 2016 (b). The photographs were taken from local newspaper websites, Pikiran Rakyat [6] and Galamedia [7], respectively.

This research is aimed to support, improve and enhance the flood early warning system by implementing hydro-meteorological knowledge into the existing system operated by Garda Caah. In this paper, the development of the Majalaya flood early warning system, abbreviated M-FEWS, and the implementation are presented. The system itself is still under development and the skill of the
system is yet to be assessed, thus this paper will also described some further research and development that could possibly improve the early warning system.

2. Majalaya Flood Early Warning System
An early warning system (EWS) was defined by UNISDR as “the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss” [8]. By this definition, an early warning system, including flood early warning system (FEWS), must be developed with aim to raise preparedness of the people that affected by the disaster far before it happen. As noted by United Nations in research by Cools et al. [9], an EWS commonly consist of four major components: 1) risk knowledge, 2) monitoring, forecasting and warning, 3) communication of an early warning, and 4) response capability. Many studies and implementation of FEWS usually focus on second and third components [9-15]. In the existing M-FEWS however, the response capability (fourth component) has been long become the part of its implementation. The communication of the early warning (third component) also has been establish very well on previous system by chaining the information to local government, private sectors and other groups and societies. Thus, to strengthen the system, this research will focus on the second component, with a little enhancement to the third components.

To improve the M-FEWS which previously built by Garda Caah, Institut Teknologi Bandung (ITB) through Weather and Climate Prediction Laboratory (WCPL) proposed to add weather prediction and automatic hydro-meteorological observations into the system. The weather prediction sub-system could give an outlook of the weather condition in the future, especially rainfall, thus increasing people alertness and enabling an earlier preparedness for the flood [12,15,16]. The automatic hydro-meteorological observation sub-system will increase M-FEWS availability and reduce the human observer misinterpretation. These two sub-systems will play important role for the enhancement of M-FEWS. Together with the warning dissemination sub-system that already exist, these three will become the key components of the new M-FEWS.

2.1. Weather Prediction
The weather prediction sub-system was developed in-house by WCPL since 2006, but implemented for M-FEWS since 2012. The weather prediction was done by downscaling the Global Forecast System (GFS) model output. GFS is a global weather forecast model run by the US National Center for Environmental Prediction (NCEP) under National Oceanic and Atmospheric Administration (NOAA). GFS was run four times daily, named cycle, on 00, 06, 12 and 18 UTC. The global forecast is available for 16 days lead time, starting from each cycle time, and available to download from NOAA server. The model spatial resolution could reach 28 km, however for this purpose the 50 km resolution was chosen to save space on server storage and maintain download speed.

The downscaling of GFS output was done using mesoscale numerical weather prediction (NWP) models, i.e. PSU/NCAR Mesoscale Model version 5 (MM5) [17] and Weather Research and Forecasting (WRF) [18] model. These models were run twice a day, using GFS cycle 00 and 12 as input, in WCPL’s 64 cores computing server. The model simulation was run for 72 hours forecast lead time, increasing its input model resolution to 27 and 9 km spatial resolution, covering Indonesia and Java respectively. Although the models could be run for longer simulation, many research suggest that our current ability to produce good prediction, especially for rain, is still bound to the first 48-72 hour, unless ensemble prediction method was used [10,12,13]. The spatial resolution of the prediction was also limited to 9 km due to limited computational resource. For longer but less accurate outlook, up to 7 days rain probabilities were also calculated using GFS output for whole Indonesia in 50 km resolution.

The downscaled weather prediction results, along with the rainfall probabilities, were disseminated through WCPL Weather website, with URL address http://weather.meteo.itb.ac.id/prediksi.php. Most of the predictions were presented in a maps (Figure 1) which require some
knowledge to fully understand it. In order to give an easier-to-understand forecast, a clickable, specific-location forecast was provided, including several locations over Majalaya and Upper Citarum area (Figure 4d).

![Figure 4. Screenshots of weather prediction results which disseminated on WCPL Weather website. (a) GFS rain probabilities map. (b) MM5 27 km rainfall prediction. (c) WRF 9 km rainfall prediction. (d) Clickable weather forecast on specific location, built on top of GoogleMaps™.](image)

2.2. Hydro-meteorological Observations

The hydro-meteorological observation sub-system was constructed using automatic instruments that measure weather and hydrological parameters. The addition of this observation system was started since December 2015. Three types of instruments were used in this observation network, namely Automatic Weather Station (AWS), Automatic Rain Gauge (ARG) and Automatic Water Level Recorder (AWLR). The instruments were placed in certain location on the Upper Citarum area, especially in the potential upstream area (see Figure 1 for the location and the type of instrument installed). Kertasari and Pacet were selected as main observation site because the main discharge to Majalaya was come from these locations. While Ibun, Drawati and Cisunggalah were also selected because it was thought that discharge from these locations also give significant contribution to Citarum section that passing Majalaya.

All of the observation instruments were self-assembled using open-source hardware and software platform. The choice of using self-assembled instruments rather than industrial built-up instruments was to reduce the instrument cost per unit. By doing so, more instruments could be used in the observation network. The AWS was built using Arduino, and equipped with quite complete weather sensors such as temperature, humidity, pressure, wind and rain sensor. Arduino is a credit card size microcontroller board that was developed in open-source paradigm, which also accompanied with
open-source software to program it. On the other hand, the ARG is a stripped version of AWS where only rain sensor that remained. To simplify programming, the ARG was built using BeagleBone, an open-source single-board computer that could run Linux operating system. The AWLR also use the same platform as ARG, since it only use one sensor, i.e. ultrasonic based water level sensor. The bottom-right part of Figure 6 shows the example of the instruments that were used in the observation sub-system.

![Figure 5](image)

**Figure 5.** (a) Screenshot of the real-time weather monitoring using AWS on Cibeureum, Kertasari. The page could be accessed on address [http://weather.meteo.itb.ac.id/observasi.php](http://weather.meteo.itb.ac.id/observasi.php). (b) Screenshot of simultaneous, real-time rainfall observations presented on GoogleMap™. Red number mark the location with heavy rainfall. The page could be accessed on the url address [http://weather.meteo.itb.ac.id/wcplfsys](http://weather.meteo.itb.ac.id/wcplfsys).

All instruments were equipped with telemetry module to send the data into the data server that located in ITB Bandung. The telemetry module use Short Message Service (SMS) to send the data. The data itself was collected every 5 minutes, however to reduce telemetry cost, the data was sent every 10 minutes. SMS was used for the telemetry because stability and availability. In some places, especially in the upstream area of Citarum, cellular network signal often very poor, thus cannot maintain internet based connectivity. On contrary, SMS service usually quite stable, even on poor network condition, thus become the only option to transmit the data.

Data from observation instruments was received by a SMS Gateway, and archived on WCPL data server. The data also automatically plotted and displayed on WCPL Weather web for real-time monitoring (see Figure 5a). For simultaneous view of the the rainfall data also plotted on top of GoogleMap™. This page serves as the main rainfall monitoring display. It will show a red color when heavy rain detected (Figure 5b).

The archived data could be used for further research by WCPL team or by other scientific community. This data will become valuable source of information to gain the risk knowledge, the first component of EWS, which have shown extensively by Borga et al. [14]. It could also be used to better understand the nature of the floods through development of rainfall-runoff model [19]. The data could also feed to the weather prediction model through data assimilation to improve forecast results [20].

2.3. Information Flow and Warning Dissemination

On previous FEWS, developed by Garda Caah, the main communication platform was the open amateur radio channel using handy talkie (HT). It was low cost and quite effective. However, because it was using open channel, it was quite hard to exchange disclosed information, especially flood possibility, in order to not create panic on society. To overcome this, the information exchange on M-FEWS was done through several methods. SMS and Internet Messenger (IM) service was used to
exchange disclosed and undisclosed information, while web (http) service and amateur radio was used only for undisclosed information.

Figure 6. The schematic diagram of information flow and warning dissemination on Majalaya Flood Early Warning System. Internet web (http), Short Message Service (SMS) and Internet Messenger (IM) was used as the main communication platform.

Figure 6 shows the schematic diagram of information flow and warning dissemination on M-FEWS. Every day, the weather prediction sub-system is downloading the global forecast and running the weather prediction model to produce rainfall forecast. The result was disseminated through web service so it could be accessed by all stakeholders and also by other people and communities as well. The hydro-meteorological observation sub-system also supplies the hydro-meteorological information every day, with 10 minutes time resolution. This information is also automatically disseminated through web service for real time monitoring. All these information could be used by Garda Caah and other stakeholders to monitor the hydro-meteorological condition over Majalaya and other Citarum Watershed area.

The flood early warning itself is managed by a closed group consist of Garda Caah and WCPL members, which named Ring 1 (blue dotted circle on Figure 6). This group communicates and discuss through IM forum. The final decision to issue warning was on Garda Caah team, as the team already has the capability to assess the flood favor condition with their local knowledge. The group existence also served as a forum for strengthens the risk knowledge of Garda Caah team, especially on weather and climate expertise. The local knowledge and capability of local stakeholders, complemented with experts qualitative opinion, were playing important role in flood warning system [15,19,21].

Flood early warning with different level of status could be issued by Garda Caah based on weather prediction and or hydro-meteorological observation. Flood warning is send to Ring 2 (red dotted circle on Figure 6), which consist of government officers, including the Head of Majalaya District, community leaders, bank and factory managers, and also the disaster management agency and
voluntary groups. The warning then forwarded by the Ring 2 to other Majalaya citizens and societies. The level of status itself is subject of further research, thus would not be discussed on this paper. By the time of this paper was written, a set of standard operational procedures (SOP) on issuing flood warning, including the level of status, was being made by collaborative effort between Garda Caah, ITB and Badan Pengelola Lingkungan Hidup (BPLHD) Jawa Barat (The Environment Management Agency of West Java Province).

Figure 7. Screenshot of an automatic heavy rain warning that was send using SMS (a). Screenshot of flood warning that issued through IM (b).

Most of the time, flood warning was start from observation data, especially rainfall observation. Upon received, the rainfall data was checked against certain threshold. If it exceed the threshold, an automatic heavy rain warning will be send to Ring 1 through SMS and IM (the heavy rain warning example was shown on Figure 7a). This is the first stage of warning. If the warning continue, and have confirmed and assessed by Ring 1, then a flood warning will be issued. This is the real flood early warning. The examples of flood early warning that issued by Garda Caah is shown on Figure 7b. This two stage warning is necessary to prevent false alarm warning because of hardware error or failure.

Currently, the rainfall threshold that being used to trigger heavy rain warning is 15 mm per 30 minutes. This value was chosen semi-arbitrary, based on heavy shower criteria by American Meteorological Society and UK MetOffice. This value also been used by Cools et al. [15] as rainfall threshold on Egypt FEWS, although for longer duration (i.e. 6 hour), as the rain rate on the study area is much smaller. This threshold value is subject to further research, because the relation between rainfall intensity-duration and flood on Majalaya is yet to known.

3. Community Involvements and the Collaboration Results
From beginning, the Majalaya Flood Early Warning System was initiated by the Majalaya community itself, i.e. Garda Caah and several other communities. As mentioned above, the initial system was operated entirely by Garda Caah. The local government of Majalaya and the provincial government of West Java have recognized that the M-FEWS was truly a community initiative and support it in
various ways. The Disaster Management Agency of Bandung Regency also has a tight relation to community, especially for disaster response activities.

The enhancements of Majalaya Flood Early Warning System by ITB, which started since 2012, did not reduce the community involvement to the system. In fact, it was expanding the “community” term because academic society is also part of the community itself. During the enhancement process, the role of the communities, not only those who live in Majalaya, but also those who lived in the upstream area, cannot be taken lightly. In the process of instruments installation, ITB team was not only helped by the Garda Caah member, but also by local people who live near the installation site (Figure 8a).

![Figure 8](image)

**Figure 8.** Photograph of AWS installation in Drawati by Garda Caah member and local people (a). Photograph of capacity building workshop on flood hazard for various societies around Majalaya and Bandung (b).

The replacement of manual observation system with technological based observation, did not remove the local observer from the FEWS. Instead, it adds their duty to look after the instruments and become the first person to contact in case of hardware failure. This necessity requiring more active involvement of the person, especially on upgrading their knowledge over the instrument itself. As noted by Baudoin et al. [21] and Gautam and Phaiju [19], local people involvement in monitoring, observation, and instrument maintenance is one key factor that sustain the existence of the Early Warning System.

In the core of M-FEWS, community still hold the biggest portion. The real flood warning still managed by Garda Caah and their partner communities. The prediction and observation sub-system enhancement was also results of collaborative effort between Garda Caah, and ITB, with support from local government and private sector (see Acknowledgement). The enhancements process of M-FEWS not only consists of system upgrade, but also a capacity building for Majalaya communities as well as other communities around Bandung (Figure 8b).

The collaborative effort to build the M-FEWS was beneficial to all stakeholders. The Majalaya communities have a quite reliable Flood Early Warning System, while ITB and or other scientific community could have dataset for research purpose. Currently, the M-FEWS is still in very early stage and not fully functioning yet. By the time of this paper written, new instruments is still being installed. The data acquisition and dissemination system is still in active development. The automatic warning system still need an improvement, and the effectiveness of the early warning system was not yet evaluated properly. Nevertheless, the existence of the flood warning system already has impact on Majalaya communities.
4. Possible Improvements for the M-FEWS

One important and basic subject to improve M-FEWS is to understanding the nature of the flood itself. This will need various dataset that related to flood, for example rain, water level and stream flow, discharge debit, sedimentation rate, river path and cross-section, land use, soil type, elevation, slope, etc. To provide these datasets, an observational campaign or research need to be conducted by corresponding institution or scientific community. Technological advancement might ease these observations, but community participatory will be very advantageous. The effort to understand the nature of the flood will also require trans-disciplinary and cross-institution collaborative research. By conducting these researches, problems like where to install the instruments, how to define rainfall threshold value, and how to estimate flood discharge arrival could be addressed more easily.

Another important research that could be done to improve the M-FEWS is to simulate the river discharge using hydrologic and or hydraulic model. As suggested by Plate [11], hydrological conversion of rainfall into runoff and discharge for large river basin cannot be ignored. Thus predicting flood using hydrological and hydraulic simulation is necessary for a better flood early warning system. A complete knowledge of the watershed that mentioned earlier will also be needed in this research. Such complex modeling will also require various skill and knowledge from different discipline, so collaboration is suggested.

Improvement on the hydro-meteorological observation is still a necessity, as the current stage of the sub-system is far from reliable. A better design on the observation system, especially power efficiency and the telemetry system is an open area to be explored. Designing cost-effective instruments will also open the possibility to expand the observation network. Rainfall anomaly detection system also need to be enhanced, as the simple single-threshold method might not suitable for triggering flood warning due to different characteristic of the observation sites. As shown by Krzhizhanovskaya et al.[22], the use of Artificial Intelligence in the rainfall (and possibly water level) anomaly detection could bring the FEWS into the next level.

The weather prediction sub-system of the M-FEWS also a broad subject of improvements. As previously mentioned, data assimilation of the existing observation into the model may improve the rainfall forecast result. Assimilation of remotely sensed data, such as radar, might also have good impact on the forecast [14]. Various researchers, i.e. Gouweleeuw et al. [10], Pappenberger et al. [12] and Thielen et al. [13], also suggest the use of the now trending ensemble forecast to provide better rainfall forecast to be used in flood early warning system. However, as demonstrated by those researchers, a data assimilation and ensemble prediction system need a lot of resources which may not be have by single institution, thus require collaboration with other institution.

Various scientific and technical problems need to be solved and fixed before the M-FEWS could be said complete. In the future, M-FEWS development could use as a framework for various research and development. It could also use as platform to raise people awareness to their environment. It could also use to strengthen cooperation between authorities and various institutions. Beyond that, it could use to assist adaptation against environmental change.

5. Summary

Majalaya Flood Early Warning System (M-FEWS) has been initiated by Garda Caah since 2008. Since 2012, ITB through WCPL, has enhance the system by adding the weather prediction system developed in-house. In the late 2015, an automatic hydro-meteorological observation system and an automatic heavy rain warning system were also added to the system.

Currently, the M-FEWS is still in very early stage and need many fix and improvement. Various possible research and development could be done to improve the early warning system. Many of those researches will require collaborative works from trans-disciplinary researcher and various institutions. The M-FEWS is a result of a collaborative effort between community, academic institution, governments and private sector. It was developed with the spirit of collaboration and cooperation, thus any collaborative works to improve it are welcomed.
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