Initial development of the digital crowd mapping for landslide monitoring and early warning system

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Abstract. Landslide disaster risk reduction emphasizing community participation and technical instruments for monitoring and early warning has been introduced in Indonesia for more than a decade. Notable recognition from the international scientific community indicated that this approach is reliable and effective for landslide vulnerable area where a dense population exists. This paper presents our progress of the initial development framework of interdisciplinary product through digital crowd mapping for landslide and early warning in mobile apps. The crowd information from local people or community in the real-time as a ‘human sensor’ is the necessary and main point in developing this crowd mapping because not all of the landslide vulnerable area in Indonesia is covered by the monitoring and early warning technical instruments. Rainfall condition, threshold condition based on the geological structure, data monitoring from field early warning instruments, and verified crowd information from local people, are occupied as the ‘requirement definition’ for ‘system and software design’ that will be structured and provided in the apps. Central Java Province is selected as a pilot area in developing this digital crowd mapping.

1. Introduction

Landslide disaster risk reduction in the vulnerable area with a dense population, such as in Indonesia, need a strong integration between appropriate technologies and community participation [10]. The active public or community-based participation here aims to achieve the sustainability of disaster management and risk reduction [9][13]. While the application of low-cost landslide early warning technologies through proper training, education, simulation drill and guidance is very important to strengthening people awareness and preparedness when the landslide took place [5][6]. A hybrid socio-technical approach for effective landslide disaster risk reduction in Indonesia has been promoted to the international disaster research community in almost a decade [10][11]. Notable achievement of this approach has been reported, for instance, in the cases of landslide disaster in Kalitelaga Village of Banjarnegara in Central Java (year 2007), Neuhun Village of Aceh Besar (2015), Guntur Macan Village of West Lombok (2016) and Tanjung Batu Village of Donggala in Central Sulawesi Province.
where the casualties are significantly prevented. Recent years, the improvement in technical and social aspects was carried out based on the input from community and local authorities, considering their distinctive environment and social condition. As a further step for advancing the research on landslide disaster risk reduction in Indonesia, this paper presents the initial development framework of the interdisciplinary product by integrating the socio-technical approach with digital technology, namely the digital crowd mapping for landslide monitoring and early warning system.

2. The Digital Crowd Mapping Framework

2.1. Overview
Roadmap for a community-based landslide disaster risk reduction in Indonesia was designed from 2003 based on the monitoring and early warning system. This roadmap divided into four phases: exploration, applied research, integration by interdisciplinary, and trans-discipline and diffusion. Basic research through exploration was carried out within 2003-2005 by studying landslide triggering and controlling factors, type and mechanism as well as mapping landslide vulnerability and danger area. Applied phase including risk prediction through numerical model and simulation with the initiation of field instrument of early warning system was performed in the year 2006-2009 [3][7]. The development of community-based landslide monitoring and early warning system with local technologies held in 2010-2014 as the phase of integration by interdisciplinary. The development of patent (for technical instruments) and national standard (for hybrid socio-technical approach) was also proposed in the mentioned period. After the system was recognized by the international scientific community [4], the diffusion phase then started from year 2015 and hopefully to 2020. As presented in this paper, the diffusion phase highlights the development plan of further generation for landslide monitoring and early warning, by digitizing the system into the product of crowd mapping and early warning apps.

2.2. Methodology
Conceptually, a framework of the digital crowd mapping is based on the rainfall condition, the movement of hills or slopes in the vulnerable area where technical instruments are installed, and combined with the ‘crowd information’ from local people through digital technology (mobile device apps). The installed technical instruments here include automatic and manual extensometer, data logger and acquisition, siren and rotary light, digital and manual tiltmeter, and automatic rainfall recorder [5][11]. The crowd information from local people or community in the real-time as a ‘human sensor’ is necessary because of not all the vulnerable area covered by the monitoring and early warning technical instruments. This combination at the end results in the online information which dynamic and interactive that can be accessed through a mobile device, in terms of the current condition in the vulnerable area from slope movements and landslides. In overall, the framework of the digital crowd mapping for landslide monitoring and early warning system as the implementation of trans-discipline and diffusion phase in the community-based landslide risk reduction in Indonesia is shown in Figure 1. The development of innovative design product and strategies for the community engagement, in this framework, is in accordance with the National Standard of Landslide Early Warning System (SNI8257:2017) [4]. While, the analysis for mapping vulnerability, landslide risk and dissemination through public communication methods are adopted based on landslide types, rainfall thresholds and hybrid socio-technical approach [1][9][10][12]. The design test of crowd mapping and early warning apps will be conducted into the community engaging with the technical instruments, to examine the effectiveness and further improvement of the overall system [4][5].

3. Results
Initiation of the crowd mapping for landslide monitoring and early warning is started from the area of Central Java Province in Indonesia. Landslide Early Warning System (LEWS) made by the Centre of Excellence of Technological Innovation for Disaster Mitigation (GAMA-Inatek) Universitas Gadjah Mada for technical instruments of the system was already installed since 2015 up to 2018. In cooperation with the National Disaster Management Agency of Indonesia (BNPB and BPBD), the
LEWS instruments totally placed in 28 locations spread in Central Java. Figure 2 shows the landslide vulnerability map of Central Java Province. The base map was originated from the Center of Volcanology and Geology Disaster Mitigation in 2014, with further analysis on geology, lithology and geomorphological conditions.

Figure 1. Research framework of digital crowd mapping for landslide monitoring and early warning system

Figure 2. Landslide vulnerability map of Central Java Province with locations of LEWS installation
The high vulnerability area is located in the zone where the occurrence of landslides is very frequent, high rainfall rate, very high weathered lithology, with lots of discontinuity in geological structures. The rainfall condition is collected from two sources: Indonesian Meteorological, Climatological and Geophysical Agency (BMKG), and grid-based rainfall from Tropical Rainfall Measurement Mission (TRMM) of NASA. In the application of crowd digital map, this rainfall data will be integrated with landslide vulnerability map and the monitoring data from technical instruments that installed in the several points. The real-time landslide warning that triggered from heavy or continuous rainfall is not solely depending on the rainfall data and vulnerability map, but also the threshold condition [12]. Rainfall threshold that contributed to landslide could be analyzed empirically from rainfall duration, cumulative rainfall, lithology, land cover, climate region and landslides in the past took place and densely archived [14]. However, the threshold in each different geological structure results in different threshold curve. For instance, three different geological structures in Purworejo Region of Central Java i.e. sandy clay, andesite intrusion and andesite breccia, gives different threshold curve [2] as shown in Figure 3.

![Figure 3. Threshold curves in Loano Sub District of Purworejo, Central Java Province between (a) sandy clay, (b) andesite intrusion, and (c) andesite breccia [2]](image)

The brief user interface of the digital crowd mapping for landslide monitoring and early warning system could be seen in Figure 4. The crowdsourcing as vital information based on the users’ involvement is categorized into four roles i.e. (1) crowd as sensors, (2) crowd as social computers, (3) crowd as reporters, and (4) crowd as micro-tasker [15]. The development of digital crowd mapping introduced in this paper, as shown in Figure 4, will go to the category of the crowd as reporters. Through this digital crowd mapping apps, people will actively report the latest (danger or vulnerable) situation of what is now happened (cracks on hills, slope movement, landslide) in their location where the rainfall occurs. To this condition, the level of involvement is active with the data or information given is semi-structured and verified by the mobile apps.

According to the above results, the main challenges for further progress in the development of the crowd mapping for landslide monitoring and early warning system is to combine all the rainfall condition (which should be updated automatically), threshold condition based on geological structure, data monitoring from field early warning instruments (yellow dots in Figure 2), and crowd information from local people, and mapped it all as the ‘requirement definition’ for ‘system and software design’.
The software development for crowd mapping mobile device apps includes the unit and system testing is still on progress.

![Figure 4. User interface for the digital crowd mapping landslide monitoring and early warning system](image)

4. Conclusion

Recently, interactive media through a mobile device is somehow crucial in providing the latest and valuable information from local people or eyewitness in terms of natural disasters [8]. The role of crowdsourcing as valuable information is now optimized in several mobile device apps particularly for disaster management cycles such as preparedness, response, recovery and mitigation [15]. Initial development of the digital crowd mapping for landslide monitoring and early warning system in this paper hopefully could advance the landslide disaster risk reduction efforts in Indonesia. Moreover, this digital crowd mapping could be a focal point in achieving the sustainability of disaster preparedness and mitigation in Indonesia which strongly involves community participation and integrates with the technical instruments.

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