# PHYSICAL VULNERABILITY MODELLING BASED ON FLOOD INUNDATION MODEL AND IMAGE MINING

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## ABSTRACT

*Flash flood disaster occurred within the City of Garut, West Java, Indonesia, on 20th September 2016, which caused many casualties and damages. Flood model could be performed to model the already-occurring disaster, as well as to depict future events that may occur to overcome any potential disasters, where the inundation flood model depicted the element at risk. In order to assist the analysis for the damages occurred, image mining could be used as part of the approach, where online media was utilized as well. The image mining resulted information about building damages caused by the flood. Afterwards, the physical vulnerability (buildings/residents) model could be further performed. Finally, the relationship between vulnerability and the flood inundation were portrayed. The resulted physical vulnerability model showed that larger height of the flood water caused higher degree of loss of the building, in which portrayed the need for total rebuild of houses as well. Considering available open source data and fast data acquisition, the approach showed such efficient approaches, where the results could be used in order to establish recommendation for building reinforcement, spatial planning, or protection wall in flood prone areas within the future time.*

Key words: *Flash flood; flood inundation model; element at risk; building damage; image mining; physical vulnerability model*

## INTRODUCTION

Indonesia always has unique problematic matters in terms of water. Apart from drought that happens occasionally in Indonesia, flood always has its own attention in the country. Water-related problems not only result technical issues, but often impact the major economic and social perspectives of the nation. Having complex socio-economic problems, weak infrastructure and high population density, such conditions show that water-related disasters may cause more casualties in Indonesia. In Garut, West Java, Indonesia, on the 20th September 2016, flash flood occurred within the area, causing many impacts. Having the city to be around 24 kilometers from the east part of the forest that maintains the Cikamiri Water Spring, Garut lies within Cimanuk Watershed, in which has a total area of 3,636 km$^2$. The flood disaster caused death of 34 people, where 19 people gone missing. Also, 1,326 people was evacuated from the area, in which 2,511 residents were damaged (⅓ of them could not be utilized at all). It was said that the disaster was one of the worst disaster happening to the city.

Water is somewhat risky to the society if it is not handled properly, especially those related to flood. However, flood events are somehow predictable if they are well-calculated, where mitigation scenarios could be carried out beforehand, therefore, hydrological modeling is significantly important. Hydrological modeling is very pertinent in terms of disaster risk, since replicating natural systems may portray potential projected situations/impacts for the future time. Mentioned by Yoon *et al* (2014), to prevent water disasters, it is essential to develop management models that could support in settling upstream with downstream interests. Based on the disaster in Garut, the flood model could be performed as well, where further studies could be attained, including element at risks and the vulnerability of the residents/settlements surrounding the area of flood.

On the other hand, as part of the flood occurred in Garut, online media indeed had their own portion in informing the disaster. The media includes social media (such as Twitter, Instagram, etc) and many Indonesian electronic news. To overcome the problem in Garut, online media could be used as one of such approaches to depict the level of damages. Overcoming the condition in Garut, to depict the flood occurrence as well as to prevent any other disasters within the future time, the integration of both hydrological modeling and image mining (from online media) could be one of the most potential approaches. Hence, this study will be relevant for related stakeholders since it can assist decision making and cost–benefit analysis of structural protection measures by assessing the potential cost of future events, which can be used as well for other types of hazards within the future time.

## METHODOLOGY

Initially, the distribution of frequency was statistically identified to obtain the recurrence interval or return period, where the geomorphological condition of the catchment area was also carried out (Figure 1). Afterwards, as soon as all hydrological parameters were attained, flood inundation modeling could be performed. The result of the flood model were then used to show the element at risk, where potential building damages were observed, based on the integration of both risk and actual damages caused, derived from image mining, available via online media. Finally, the correlation between the resulted damages and resulted model could be depicted. The resulted model includes both velocity and depth value of the flood inundation.

### Watershed Delineation, Frequency Distribution, and Design-storm Peak Discharge

The watershed delineation work was done based on the topography data provided by The Indonesian Geospatial Agency (*Badan Informasi Geospasial*), with contour data of 1:25,000. On the other hand, the rainfall data was derived from Garut's local Indonesian Agency for Meteorological, Climatological and Geophysics (*Badan Meteorologi, Klimatologi, dan Geofisika*). The rainfall data used for this study was 10 years, starting from 2002 to 2011. The frequency distribution was statistically calculated as well using the Gumbel Method (Al-Mashidani *et al*, 1978), to gain the peak designed precipitation. Afterwards, the design-storm peak discharge was further calculated using the rational equation (Kuichling, 1889). The values was then ready to be inputted to further perform the flood inundation model.

### Flood Inundation Modeling

Flood inundation modeling was done using Hydrologic Engineering Center – River Analysis System (HEC-RAS) software developed by the U.S. Army Corps of Engineers (USACE). As part of the modeling process, the determination of geometric parameters for the system was carried out using HEC-GeoRAS software. The software enables users to perform the geometry of the specified stream based on its original topography. Within the process, parameters such as cross sections, channel banks, stream lines, as well as hydraulic parameters were calculated and were ready to be imported to HEC-RAS. Afterwards, in HEC-RAS, all related hydrological data (100-year return period) was then inputted to perform flow analysis, in which resulted the flood model inundation.

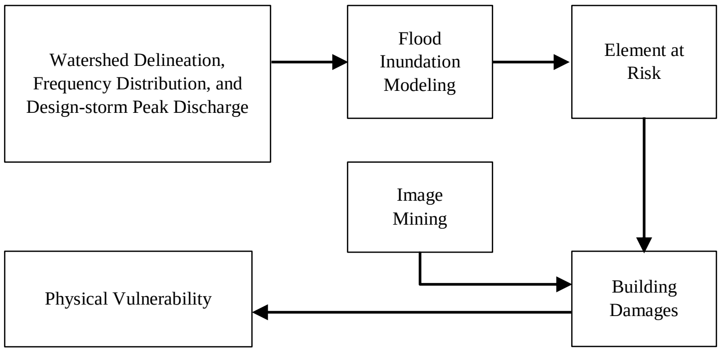


Figure 1. Methodology flow chart

**Image Mining**

Internet, especially website and social media such as Facebook, Instagram and Twitter has accumulated a huge number of images contributed by their users. Filtering and downloading images automatically from internet using Application Programming Interface (API) from each of these social media and Google images or custom search API are available. Furthermore, with regard to disaster (demonstrating the impact of disaster), the images that can be used in this research must have two mandatory information, i.e. time and geolocation.

Mostly all images provided the time information in metadata or otherwise automatically or manually extract the time information from the posting time, caption of the images or from the text of articles are available. Whist for geolocation, a large portion of images uploaded to internet contain no geolocation information. Basically, the geolocations of images or photos in internet come from two sources: 1) With GPS-enabled cameras or gadgets, geolocations can be automatically extracted from the images or associated with the post in social media; 2) Users can also manually geotag photos by dragging a photo to a point on a world map interface or specific location name when uploading photos to an image sharing service or social media (Bo *et al*, 2014).

**Element at Risk**

An essential part in methodologies for the assessment of hazard - risks and vulnerabilities of physical and social structures is the identification and valuation of an inventory of objects and assets exposed to a certain hazard. The risk of an asset or element at risk is then expressed in its tendency to get damaged (Douglas, 2007). In the framework of the International Strategy for Disaster Reduction (ISDR) the term risk is defined as the “probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environmental damage) resulting from interactions between natural or human - induced hazards and vulnerable conditions” (ISDR, 2004).

Consequently, risk assessment is based on a methodology to evaluate the nature and extent of risk determined by characteristics of potential hazards and conditions of vulnerability that could potentially harm people, their properties and the environment (ISDR, 2004).

In the evaluation of the risk that a certain element might be affected by a natural hazard, the exposure of the element has to be evaluated. The term exposure “refers in general to the volume and concentration of elements in a given area, and is calculated combining population exposure, density of population, built area, industrial area, and Government and institutional area” (Villagrán de León, 2006).

Thereby the distribution and characteristics of elements at risk can define physical exposure to natural hazards, e.g the susceptibility to be affected by natural phenomena: “Elements at risk, an inventory of those people or artefacts that are exposed to a hazard”.

**Building Damages**

The main focus in this study is about the damage to the building units as an impact of flash flood. Damage to the building is recognized based on the information of the physical condition of each unit derived from photo images of buildings of various social media such as Facebook, Instagram and Twitter in the period of time of the incident and after the occurrence of Garut flash flood. The level of building’s damage was based on physical criteria damage to buildings published by the Bakornas PB (Bakornas in Dept. PU, 2006) and was specially modified for flood damage in 2012 (Rijal, 2012).

**Physical Vulnerability**

Physical vulnerability is the potential damage defined by physical structure (material and construction building) when disaster occurred (Ebert *et al*, 2009). It can also be defined as the degree of loss to an element at risk (UNDRO, 1984). The vulnerability assessment is important for the development of disaster risk reduction strategies. Vulnerability is usually expressed as the value from 0 to 1 expressing the degree of loss due to the impact of the process. The relationship between vulnerability and the process of disaster is often described with vulnerability curve. The curve could be a valuable tool for the local authorities because it can assist decision making and cost–benefit analysis of structural protection measures by assessing the potential cost of future events. This can also be used for other types of hazards in the future. The vulnerability curve represents the function of the intensity of the process and the degree of loss.

## RESULTS AND DISCUSSIONS

**Watershed Delineation, Frequency Distribution, and Design-storm Peak Discharge**

Prior undertaking all related flood modeling work, the geomorphological feature of the watershed/catchment area was required to be attained by delineating the watershed based on a specified downstream point. The delineation of catchment area is needed since the area will be specified to those areas that affected the downstream area only (Figure 2).


Figure 2. Catchment area with Copong Dam as downstream

The delineation was based on elevation data (1:25,000 scale) provided by the Indonesian Geospatial Agency (*Badan Informasi Geospasial*). The contour data was converted to Digital Elevation Model (DEM), and was used as the base for the delineation. For this study, the downstream point was Copong Dam, located at 821606 mE and 9204322 mN. Since the outlet of the catchment area was Copong Dam, the catchment area that potentially affected the downstream was 471.32 $km^2$.

Precipitation data was attained from local measurements, provided by Garut's local Indonesian Agency for Meteorological, Climatological and Geophysics (*Badan Meteorologi*, *Klimatologi*, *dan Geofisika*). The rainfall data used for the analysis was 10 years, starting from 2002 to 2011. From such data, as for the frequency distribution, the Gumbel Method was used for the analysis. With 100 return year period, the design rainfall was 228.03 mm. From the aforementioned design precipitation, the maximum design-storm peak discharge was then calculated as well, i.e. 304.14 m3/s.

**Flood Inundation Modeling**

Based on hydrological parameters gained, the flood model could be performed. The establishment of the model used Hydrologic Engineering Center – River Analysis System (HEC-RAS). The determination of the geometric parameters were based on the DEM data carried out previously, assisted by HEC-GeoRAS software. As for this analysis, 100-year flood return period (1% annual probability) was chosen.

From the analysis, the distribution depiction for the flood inundation was achieved. Based on the model, as results, both depth and velocity of the flood model was attained as well (Figure 3).

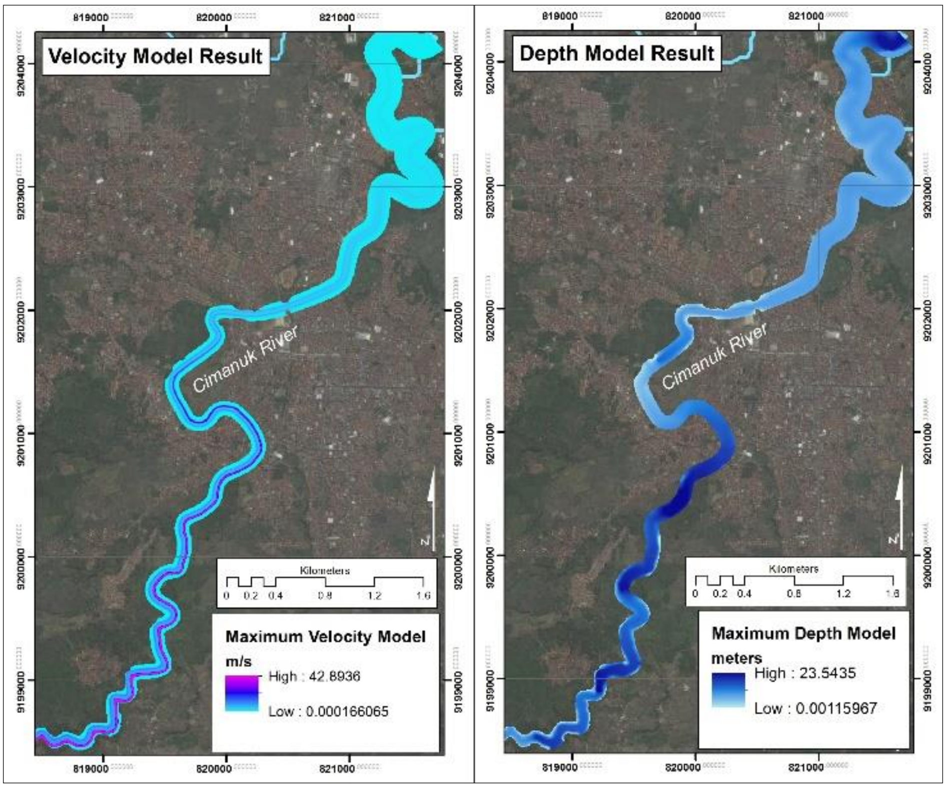


Figure 3. Flood inundation model results - velocity model (left) and depth model (right))

**Image Mining**

With regard to image mining, in most cases, the number of disaster related images that have valid time and geolocation will be very small and not representative, therefore manually finding and giving geolocation for images related with the disaster is necessary. However, giving geolocation for images manually can be very difficult and error prone, especially if users are not really familiar with the location and only have little information pra and post disaster. The workaround for this issue is only looking for special landmarks or points of interests which are easily recognizable and unambiguous, such as school, hospital, mosque, government offices, etc. The steps can be began by finding the specific landmark around the disaster site, obtaining the geolocation, and afterwards finding the landmark images, or vice versa starting with a list of existing landmark images. The point location for each area was then inputted to derive a spatial representation of the relevant objects. In the last step of our methodology, the extracted data can be intersected with hazard maps to derive an indication about the exposure of the identified elements at risk. This approach of identifying elements at risk could be equal for every hazard.

Based on image mining approach, in the HEC-RAS model, corresponding to the essential facilities, the database of facilities for the city boundary of Garut was identified. Our study results showed that 43 buildings were damaged with the flash flood in the City of Garut (Figure 4). The intersection with a flood-hazard map for Garut resulted a list of five classes of the category of "element risk" exposed to flood-hazard (Table 1).

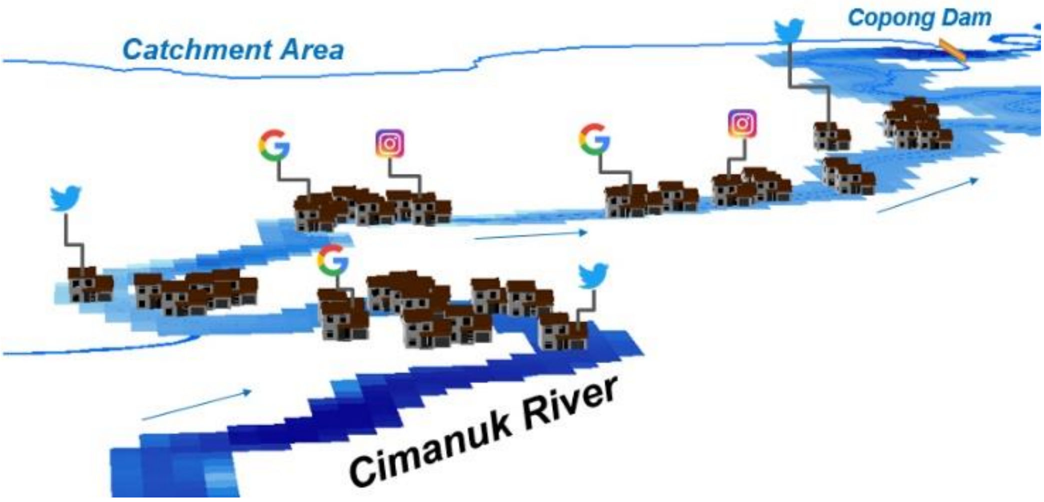


Figure 4. Element at risk depiction of essential facilities (residents/buildings)

GIS. The results for the image mining were the determination of 43 buildings surrounding the area of flood to be indicated as damaged (Figure 4), which is further described on Section 3.4 and 3.5.

### Element at Risk

Based on the previously described methodology, a case-study for flood prone areas of the city of Garut was carried out to identify elements at flood risk of the category of essential facilities (residents/buildings).

The identified tags by image mining approach were then extracted from the database on a map as point-information to

### Building Damages

Criteria of building damages as a result of flash flood for each level of damage can be seen in Table 1. Based on physical criteria on Tables 1, images of each building identified the extent of the damages. The main problems encountered was that most of the images were not complemented by location identifiers (coordinates) so that the identification of the building was only done to the building which was the city landmarks such as hospitals, schools and government offices. City landmarks were easily recognizable to obtain the identity of its location. The results of the identification of

Table 1. Physical criteria to identify level of the building damage casused by flood

| No | Level of Damage | Damage Criteria |
|---|---|---|
| 1 | Collapsed | Buildings are collapsed by flooding, where the overall building is buried by flood or most structures are damaged (inundated >50 cm and > 50 % part of building collapsed) |
| 2 | Severely Damaged | The building is still complete, but most of the structural components and architectural components are damaged (inundated max 50 cm) |
| 3 | Moderately Damaged | The building is still complete, but small part of the structural components and architectural components are damaged (inundated > 30 cm) |
| 4 | Slightly Damaged | The building is still complete, but no structural components are damage and only architectural components are damaged (inundated < 30 cm) |
| 5 | Non Damaged | The building is still complete, but no structural components are damage only inundated by flood (inundated < 20 cm) |

Garut city landmark building damage is seen in Table 1 and Figure 5.

Using coordinate information, each level of building damage can be mapped to see the distribution of the damage. Overlay distribution of damage map and the expansion of the inundation can be analyzed, showing the spatial impact of the flood occurring to the building (Figure 6).


Figure 5. Images and level of damage classification

## Physical Vulnerability

The intensity of the Garut Flash Flood had been done on the basis of the flood height and flood velocity. The degree of loss was evaluated based on the damage assessment as the impact of flash flood. The photographic documentation obtained from image mining technique was used in order to assess the damage of the building. Following the assessment of flood intensity, the pictures showing the damage of each building were analyzed. The relation between the intensity of the flood and the degree of loss for each building is plotted in a two dimensional chart (Figure 7 and Figure 8). The vulnerability curve shows that the larger the height of the flood water, the higher the degree of loss of the building. The curve becomes significantly steeper after the intensity of 6 m. The degree can also show the need for total rebuild of houses. The needs for total rebuild of houses starts with the intensities of 6 m.

The developed vulnerability curve can be applied in the risk assessment regarding

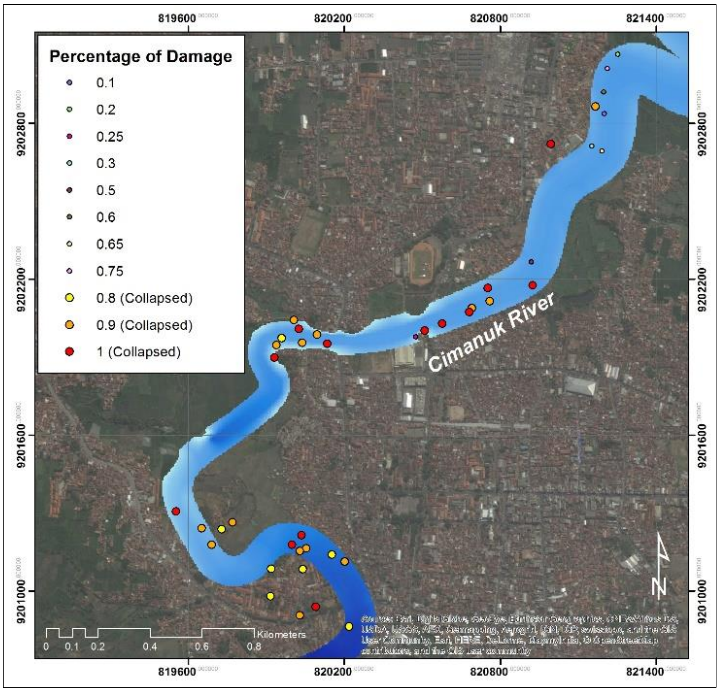


Figure 6. Spatial depiction of the damaged residents

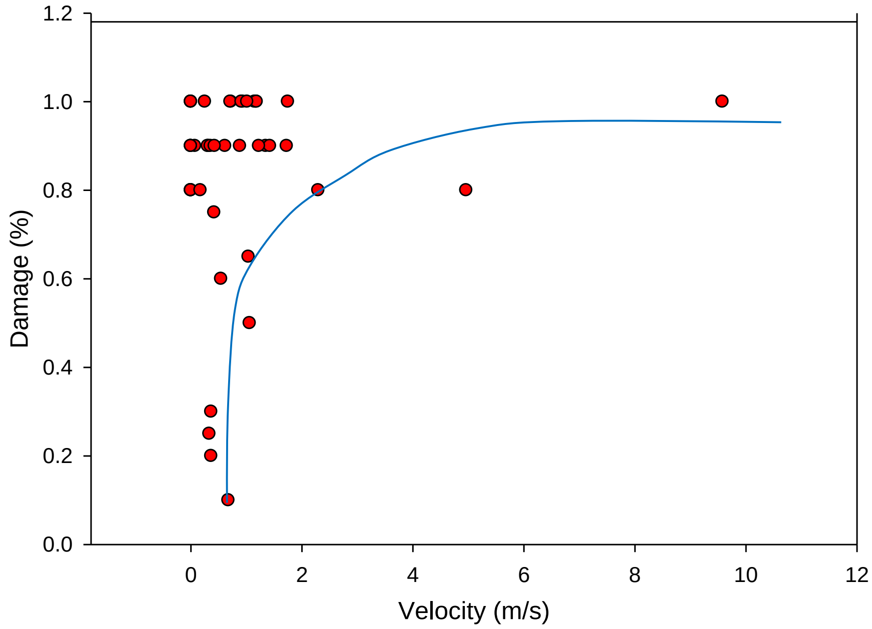


Figure 7. Correlation between damage and velocity

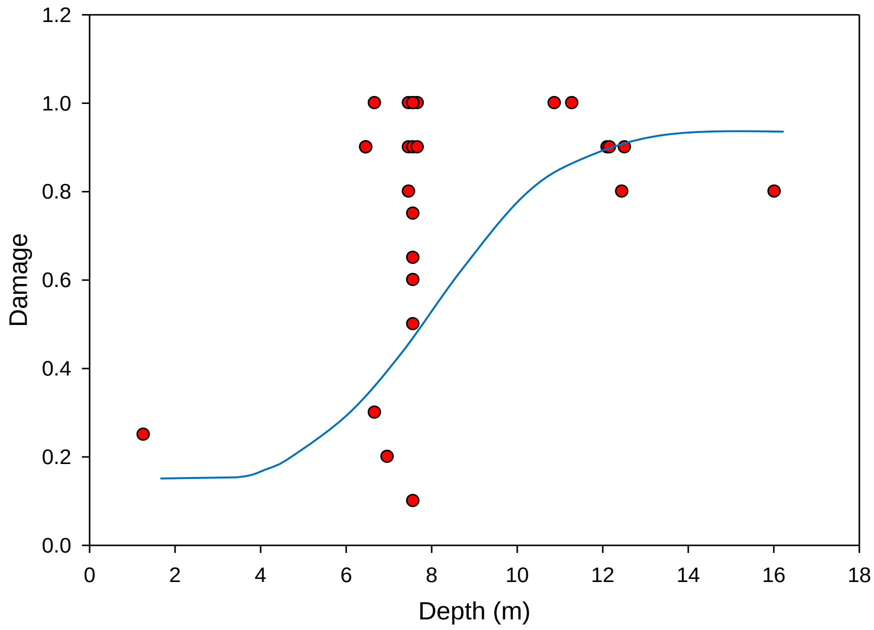


Figure 8. Correlation between damage and depth

flash flood events. The information derived from vulnerability curve is important for risk management. It could be used in order to make recommendation for building reinforcement, spatial planning, or protection wall in flood prone areas. Possible recommendations for specific objects to reduce their vulnerability could include keeping the distance from the river. The end users can employ the curve not only to calculate the costs of a future damaging event of a specific intensity but also to calculate the costs of an event if the position of the building changes. The cost-effectiveness of measures strategy including protection measures can also be analyzed by using the vulnerability curve. Protection measures such as wall can change the intensity of the flood on specific building. For example, the intensity of the flood on the specific building will be reduced by introducing a protection wall in a segment of river bank.

## CONCLUSION

Considering available open source data and fast data acquisition, the study showed that that inundation model and image mining is one of such efficient approaches to depict the correlation between damage level of physical features (buildings/residents) and the flood inundation (velocity and depth) of the already-occurring flood disaster and potential future events. The resulted physical vulnerability model showed that larger height of the flood water caused higher degree of loss of the building, where it portrayed the need for total rebuild of houses as well. The results could be used in order to make recommendations for building reinforcement, spatial planning, or protection wall in flood prone areas within the future time.

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