Empowering local leaders in flood inundation mapping in Bagelen, Purworejo, Central Java

This article discusses the reliability of flood inundation information that is obtained from participatory mapping. The commonly applied method to map flood inundation requires both direct and interpretive measurement data based on remote sensing images. Such assessments have limited availability of data; as a result, participatory mapping has become the solution. A number of studies have conducted participatory mapping to obtain flood hazard information in areas with limited sources of data, however, there has been little discussion about its reliability. This research conducted participatory flood inundation mapping by involving local leaders as respondents. The mental map drawn by the local leaders was digitised to obtain a shapefile format map. The information obtained from the semistructured interview was then included in the geographic information system (GIS) data as attributes. The obtained information was compared with the field data to determine its quality. A literature study was then conducted to discuss how the participatory mapping could support managing a disaster. Information obtained through participatory mapping can be effectively applied to disaster management because of its precise location information, lower cost and less time-consuming nature. The reliability of the information has weak accuracy of quantitative data; however, it has advantages in terms of qualitative data, especially in the detailed descriptions of flood information. In the future, participatory mapping should rely on integrating the perspectives of cross-disciplinary researchers, a comprehensive study of multidisciplinary knowledge and level of understanding of the stakeholders.

Keywords: disaster management; flood inundation; hazard; participatory mapping; reliability.

Introduction

Information on flood inundation that is important in disaster management is flood extent, flood depth, flood duration and time of occurrence, especially if it occurs in the coastal alluvial plain area. Some flood information for disaster management could be derived from modelling techniques (Thapa et al. 2020:1–12; Tu et al. 2020:1–13; Van Den Bout & Jetten 2020:1–9); however, this method requires a series of data that is measured for a long period (Ahmadalipour & Moradkhani 2019:1–13; Fernandez et al. 2016:265–280; Shrestha et al. 2020:1–17). Not all watersheds in Indonesia have accurate measurement data to be able to conduct flood hydrology models (Fulazzaky 2014:2000–2020); furthermore, flood duration data could not be derived from modelling processes (Singh et al. 2020:1035–1046; Unduche et al. 2018:1133–1149).

The participatory approach is mostly used to collect flood hazard information such as real-time measurement data of flood inundation events and supporting data required for quantitative hazard assessments in areas with limited data (Bizimana & Schilling 2010:99–126). Participatory mapping is an approach to obtain information based on local knowledge by involving local communities in its implementation (Obermeyer 1998:65–66). This approach can involve the community directly (Kienberger 2014:269–275; Singh 2014:161–173; Sudaryatno, Awanda & Pratiwi 2017:1–8) and use the community leaders as the people’s representation (Chingombe et al. 2015:1029–1040). Participatory mapping is mostly performed using traditional methods such as a printed map (Kienberger 2014:269–275; Singh 2014:161–173; Sudaryatno et al. 2017:1–8) and modern information system technology (Koski et al. 2021:1347–1365; Pocewicz et al. 2012:39–53).

Research area and methods

Research area

The research was conducted in the Bagelen subdistrict of Purworejo Regency, Central Java, Indonesia. The Bagelen subdistrict has a humid tropical climate with an average monthly rainfall of 250–350 mm, with the highest rainfall occurring in October (1100–1600 mm). The flood hazard in this area is the result of a combination of factors, such as the characteristics of the landscape, which is lowland with an alluvial soil cover, and the high water level near the riverine system.
of 376.6 mm per month (Purworejo Regency Statistical Center Agency 2019). The Bagelen subdistrict has reliefs of hills and plains, including fluvial, denudational and fluviomarine landforms (Mei, Sudibyakto & Kingma 2009:71–91) (Figure 1). The research area consists of six flood inundation-prone villages: Dadirejo, Bapangsari, Bugel, Krendetan, Bagelen and Kalirejo (Figure 1).

The land use of the flood inundation-prone villages of the Bagelen subdistrict are dominated by crop fields and settlements (43.96% and 38.99%, respectively). Forty-four per cent of the total population in the Bagelen subdistrict are in this flood inundation-prone area; therefore, the people in the area are used to flooding. Several flood mitigations measures have also been conducted by the local community, such as raising the foundations of houses, elevating livestock vehicles and increasing the number of floors of the houses, as well as adding an attic for shelter and emergency storage when a flood inundation occurs. The existing structural flood mitigation measures include drainage system networks, flood walls and gabions.

Methods

The participatory mapping method and semistructured interview was conducted in March 2020 to collect flood inundation hazard information in the Bagelen subdistrict. During the rainy season, from October 2020 until April 2021, there was no new information related to flood inundation in the study area.

In simple terms, participatory mapping is defined as an approach to obtain information based on local knowledge by involving the local community in its process (Obermeyer 1998:65–66). In a more advanced definition, participatory mapping is considered a method that can change the traditional mapping paradigm from one that seems ‘top down’ to a new mapping paradigm that is able to accommodate everyone’s interests (Goodchild 2007:8–10). In recent years, most participatory mapping activities have been classified into six categories based on their purposes, such as disseminating information to outsiders, recording and storing local knowledge, planning land use and managing resources, promoting changes, increasing community capacity and resolving local conflicts (Corbett 2009). The participatory mapping carried out in this study emphasised the purpose of recording and storing local knowledge.

There are some data required to provide an overview of the problems and conditions associated with the research location before conducting participatory mapping (Bizimana & Schilling 2010; Kienberger 2014:269–275; Sy et al. 2016), such as:

1. Aerial photographs of villages in the Bagelen subdistrict obtained from Google Satellite with a scale of 1:5000.
2. A contour map with 1 m intervals obtained from the processing result of a digital elevation model (DEM) using advanced land-observing satellite (ALOS) phased array type L-band synthetic aperture radar (PALSAR) in 2011 with a resolution of 12.5 m × 12.5 m.

The selection of the respondents

The respondents were selected through a purposive sampling technique performed prior to the participatory mapping process. Indigenous people with deep knowledge of the area became our criteria in selecting respondents. The respondents involved in this study were local leaders from village areas where flood inundation regularly occurs. The local leader (head of the subvillage) was chosen to be the respondent with the assumption that they are highly knowledgeable in the area. According to Purworejo Regency Regional Regulation Number 7 of 2008, the head of the subvillage has a working period until they are 60 years old.

The selection process of the respondents was started by collecting information about the flood inundation-prone villages. Information on the flood inundation-prone villages in the Bagelen subdistrict was collected through confirmation of a macroscaled map of the areas by the head of planning, evaluation and general affairs of Bagelen subdistrict (Figure 2).
Based on the confirmation from the head of planning, evaluation and general affairs of the Bagelen subdistrict, there were six villages prone to flood inundation. Twenty-two out of the 29 subvillages in flood inundation-prone villages of Bagelen subdistrict experienced flood inundation every year; therefore, the heads of the 22 subvillages become our respondents.

**Data collecting process through participatory mapping**

The base map for the participatory mapping process was produced by overlaying aerial photographs of the villages prone to flood inundation with a scale of 1:5000 and the contour map derived from a DEM. The aerial photographs were interpreted to obtain information on elements at risk of flooding. The information on elements at risk of flooding was not only utilised to collect information on flooding areas but also to gather evidence of flooding (by flood marks imprinted on a resident’s house wall, for example). The local respondents then made a map on the base map (containing information on contours and elements at risk) of the flood inundation hazards in their working area (Figure 3). A paper-based participatory mapping was chosen in order to acquire more intensive participation from the respondents (Aditya 2010:119–147).

The maps drawn by the local leaders from their experience were then digitised into a shapefile. Information about the characteristics of the flood inundation was used as attribute data on the map created by the local leaders.

The flood inundation map was generated based on the worst flood inundation event that occurred in the study area with the assumption that future floods will occur in a similar location place. Semistructured interview techniques were also conducted to obtain qualitative data on the flood inundation characteristics. The flow of the research method used is shown in Figure 4.

**Reliability assessment**

To determine the reliability of the participatory mapping data obtained, a comparative and descriptive qualitative analysis was performed to determine the quality of the data. The quality of the participatory mapping-derived data consists of positional (geographic or geometric), attribute,
conceptual and logical accuracy and precision variables (Devillers & Jeansoulin 2006:31–42; Shekhar & Xiong 2007). In this article we will only assess positional (geographic or geometric) accuracy and attribute accuracy.

The positional accuracy was determined by studying the literature on the geometric accuracy of the base maps used in the study. The attribute accuracy assessment was conducted by comparing the data obtained from respondents with the data collected in the field. The attribute accuracy assessment was carried out only on the flood depth parameter because the accuracy and precision of the flood extent parameter can be obtained through the assessment of geometric accuracy and precision, whilst the attribute accuracy assessment on the flood duration attribute was not conducted because there was no real-time flood duration data available as the control data.

Flood depth information was collected through flood marks that are still imprinted on local residents’ houses. Thus, the sample used is a resident’s house that still has signs of flood inundation in 2019. From these criteria, 47 samples were obtained to assess the accuracy of the flood depth data. After the quality of the data generated from participatory mapping was ascertained, the reliability of the data on disaster management based on the existing literature was discussed.

Ethical considerations

The study was conducted with the approval from the Dean of Faculty of Agriculture, Universitas Gadjah Mada (reference number: UN1/PSASDL/TU/LL/2022). This study has followed the provided guidelines for study procedures.

Results

Respondents

The respondents in this study were the heads of flood inundation-prone subvillages of the Bagelen subdistrict (22 respondents, Table 1), the heads of flood prone villages (six respondents) and an official from the government of the Bagelen subdistrict (one respondent), chosen through a purposive sampling technique. All the local leaders involved in this study were younger than 60.

Flood inundation in the Bagelen subdistrict

Flood inundations occur every year in the Bagelen subdistrict during the peak of the rainy season. The largest flood inundation event ever in the Bagelen subdistrict was used as a reference in collecting flood inundation information and mapping the flood inundation hazards, with the assumption that future flood inundation events will occupy the areas hit by this event. Based on semistructured interviews conducted with the local leaders, the largest flood inundation events in the Bagelen subdistrict occurred in 2019 (Dadirejo, Bapangsari, Bugel, Krendetan, Bagelen village) and 2016 (Kalirejo village). The flood inundation in 2019 was ascertained to be larger than the flood inundation in 1965 and similar to the one in 2004. Information regarding the year of the largest flood inundation event is in accordance with the statement of the head of Bapangsari village that the 2019 flood inundation was the largest event after the flood inundations in 1965 and 2004:

‘[R]elated to floods, this area is sure to experience flooding every year, ma’am. But last year’s flood was the most intense. Since my childhood till now, the largest floods were the 1965, 2004 floods and last year’s floods, ma’am.’ (Local leader, Male, Bapangsari Village)

Information about the largest flood inundation events in 2019 and 2016 was also confirmed by the statement of the head of Bagelen village that in the 2019 and 2016 flood inundations, the high flood level caused water to enter the building:

‘[T]he largest flood that happened here was last year’s flood, ma’am. The water gets into the office here. Usually, the water just reaches the yard.’ (Local leader, Male, Bapangsari Village)

| Number | Village               | Subvillage                      |
|--------|-----------------------|---------------------------------|
| 1      | Dadirejo              | Karangjambu, Kuwojo, Jurangkah and Karangnongko |
| 2      | Bapangsari            | Joho, Sangkalan, Bapangan, Srapah, Pucungan, Bojong and Sudimoro |
| 3      | Bugel                 | Sembir and Bugel                |
| 4      | Krendetan             | Sempurwung                      |
| 5      | Bagelen               | Kalidiren, Segeluh, Kalibelung, Bedug, Gatep and Bagelen |
| 6      | Kalirejo              | Keposong and Kahuripan          |

Source: Purwitaningsih, S., 2020, ‘Flood mitigation strategies in agropolitan area of Bagelen Sub-District, Purworejo Regency (in Indonesian with English summary)’, Master thesis, Universitas Gadjah Mada, Yogyakarta.
The shapefile of the largest flood inundation distribution that occurred in the Bagelen subdistrict was obtained by digitising the map made by the local leaders. The area affected by the largest flood inundation in the study area reached 856.63 ha or 44.83% of the area of the flood inundation-prone villages (Table 2).

Flood inundation hazard characteristics

It is important to know the characteristics of the flood hazard to select future mitigation measures. Information on the characteristics of the flood inundation hazards in the Bagelen subdistrict was obtained through participatory mapping completed with semistructured interviews.

The flood that occurs every year including the largest flood in 2016 and 2019 were an overflow of the Bogowonto River and its tributaries, which are upstream of the Bagelen subdistrict. A flash flood has never occurred in the Bagelen subdistrict. This information was obtained from the statement of the head of subdivision of planning, evaluation and general affairs of Bagelen subdistrict:

‘Here, the floods are usually due to Bogowonto, ma’am. It is also caused by the trapped rainwater that cannot reach into the channel. There has never been a flash flood here.’ (Government official, Male, Bagelen subdistrict)

The flood depth information was collected through a map drawn by local leaders of the Bagelen subdistrict. The map was also accompanied by qualitative data obtained from the interview. Most of the respondents mentioned the flood depth using their own measurements, such as ankle-depth, knee-depth, waist-depth, windowsill-depth, to the roof of the house and even more. However, we then tried to ask more about their perception of the flood depth using metres. Based on the perceptions of the local leaders, the depth of the largest flood inundation that occurred in the Bagelen subdistrict varied from less than 0.5 m to more than 3.5 m. This flood depth range was found throughout the area of the Bagelen subdistrict. However, the deepest flood depth was found in the Bapangsari village (more than 3.5 m). The local leaders said that the depth of the flood inundation reached the roof of the house. In Dadirejo village, the southernmost village of the Bagelen subdistrict experienced a depth of approximately 0.5 m – 2 m (the flood depth varied from knee-depth to the upper wall of the house). Bugel village experienced a flood depth of approximately 1 m – 1.5 m (the flood inundation varied from waist-depth to windowsill-depth). The Krendetan and Kalirejo villages experienced a depth of approximately 0.5 m – 2 m (the flood depth varied from ankle-depth inside the house until it reached the roof of the house). In Bagelen Village, the flood depth was approximately 0.5 m – 2 m (varied from knee-depth to the upper wall of the house). The flood depth map of Bagelen subdistrict is exhibited in Figure 5.

The largest flood inundations in the Bagelen subdistrict had a duration of less than 24 h. Kalirejo village, Bagelen village and some parts of Krendetan village experienced flooding for no more than 6 h. This information is in accordance with the statement of the leaders of Kahuripan and Kalibelung subvillage:

‘The largest flood in 2016 was about half a day, ma’am; then it was receded.’ (Local leader, Female, Kahuripan subvillage)

‘The last flood didn’t take long time, ma’am; it took about 3 or 4 h and then continued to recede.’ (Local leader, Male, Kalibelung subvillage)

Some parts of Krendetan village specifically located near Bugel village experienced flood inundation for up to 12 h:

| No. | Village | Area (ha) | Area affected by flood inundation (ha) | Percentage (%) |
|-----|---------|-----------|---------------------------------------|----------------|
| 1   | Dadirejo| 539.55    | 109.81                                | 20.35          |
| 2   | Bapangsari| 368.21    | 192.64                                | 52.32          |
| 3   | Bugel   | 151.20    | 151.20                                | 100.00         |
| 4   | Krendetan| 345.82    | 237.61                                | 68.71          |
| 5   | Bagelen | 253.02    | 96.84                                 | 38.27          |
| 6   | Kalirejo| 252.84    | 68.53                                 | 27.10          |
| Total|         | 1910.64   | 856.63                                | 44.83          |

Source: Purwitaningsih, S., 2020, ‘Flood mitigation strategies in agropolitan area of Bagelen Sub-District, Purworejo Regency (in Indonesian with English summary)’, Master thesis, Universitas Gadjah Mada, Yogyakarta
The flood around the paddy fields area was longer; it was almost all day, ma’am.’ (Local leader, Male, Semawung subvillage)

Most of Bapangsari village experienced flood inundation for up to 24 h. The western part of Bapangsari village experienced flood inundation for 24 h, whilst the eastern part experienced flood inundation with shorter duration. This is in accordance with the information provided by the head of Bapangan subvillage. The subvillage itself is located in the western part of Bapangsari village:

‘[I]n this area, the floods took longer, ma’am. In the morning, around half past 8, the water started to enter the village; then it subsided only the next morning. It was about 23 h or more.’ (Local leader, Male, Bapangan subvillage)

‘Around 7 pm, the water started to rise; then around 7 am, it receded, ma’am.’ (Local leader, Male, Bapangan subvillage)

Information about the flood duration is presented in spatial form in Figure 6.

**FIGURE 6:** Flood duration map.

![Flood duration map](source)

It is important to compare the data collected through participatory mapping with the data directly collected from the study area to know its accuracy. However, from three parameters (flood extent, flood depth and flood duration), there will only be one hazard parameter to be compared with the data from the field study, the flood depth.

The validation of the flood extent parameter was not conducted because of the high accuracy of the instrument utilised in the participatory mapping process and the high data confidence by the respondents involved. The base map for participatory mapping was created from aerial photographs and a contour map of the Bagelen subdistrict. The aerial photographs were from Google Satellite, which has geometric accuracy that meets the accuracy standard of a Class 3 base map at 1:5000 scale (Akbar 2018). The contour map is the result of contour analysis from DEM ALOS PALSAR with a pixel size of 12.5 m × 12.5 m and vertical accuracy of 0.8 m (Julzarika & Dewi 2018:11–24). Both the aerial photographs and contour map used for the base map have high geometry accuracy.

Furthermore, the respondents involved in this research were local leaders from 22 subvillages that are prone to flooding. The local leaders are native persons of the subvillage and based on the local regulation (Regulation of the Government of Purworejo Regency No. 7/2008), the local leaders are supposed to lead the subvillages (which have small areas) until they are 60 years old. Therefore, they have lived in the area for a long time and have rich knowledge of their area, so the level of detail of their description of the location and other flood hazard information is very high (up to the name of the person whose house was affected by the flood and the part of the house that was flooded), representing high data confidence. The exception is also in accordance with the statement of Servigne, Lesage and Libourel (2006:179–185) regarding validation of data through validation of geometric accuracy, where the geometric accuracy could become the validation measure of information accuracy if it is related to a location as an attribute. At this point, flood extent is information related to location. Validation of the flood duration cannot be conducted because of the represent reality accurately. Data quality has many dimensions, such as accuracy, accessibility, completeness, consistency, integrity, validity and currency (Batini & Scannapieca 2006). In this research, the determination of data quality was based on its accuracy and accessibility. Accuracy shows the degree of the information depicted on a map matched with the information in the real world (Shekhar & Xiong 2007). In the geographical and geospatial domain, the accuracy of a map consists of positional accuracy and attribute or thematic accuracy. Positional accuracy indicates the accuracy of geographical position (horizontal and vertical accuracy), and attribute or thematic accuracy presents the value accuracy of the properties (Batini & Scannapieca 2006).

Discussions

**The quality of data obtained through participatory mapping**

Data quality could be defined as the degree of how well data can serve its specific purpose. High-quality data can
TABLE 3: Compatibility assessment of the information obtained from the respondents and the field data.

| No. | Code of polygon | Maximum flood depth based on the perceptions of local leaders (m) | Flood depth based on observation (m) | Compatibility |
|-----|----------------|---------------------------------------------------------------|-----------------------------------|--------------|
| 1   | KJRT2          | 1.0–2.0                                                      | 0.15; 1.78; 1.95                  | Matched      |
| 2   | SGrT1          | 1.5–2.0                                                      | 1.14; 1.36                        | Matched      |
| 3   | BGRT2          | 1.5–2.0                                                      | 2.28                               | Not matched  |
| 4   | BDRT1          | 1.5–2.0                                                      | 2.00                               | Matched      |
| 5   | PSRT1          | < 1.0                                                         | No data                           | No data      |
| 6   | KRRT3          | 1.0–1.5                                                      | 0.50; 0.76                        | Matched      |
| 7   | KJRT5          | 1.0–2.0                                                      | No data                           | No data      |
| 8   | BJRT1          | 1.0–3.0                                                      | 1.46                               | Matched      |
| 9   | BGRT3          | < 1.0                                                         | 1.43; 1.23; 1.23                  | Not matched  |
| 10  | SRRT1          | 1.5–2.0                                                      | 1.22                               | Matched      |
| 11  | BGR1T          | 1.0–1.5                                                      | No data                           | No data      |
| 12  | KHR1T          | < 1.0                                                         | 0.55                               | Matched      |
| 13  | KHR1T5         | 1.0–1.5                                                      | 0.60                               | Matched      |
| 14  | PSRT4          | 1.0–2.0                                                      | 0.47                               | Matched      |
| 15  | PSRT5          | 0.5                                                          | No data                           | No data      |
| 16  | BGRT2          | 1.0–1.5                                                      | 1.14; 0.28                        | Matched      |
| 17  | SBRT2          | 1.0–1.5                                                      | No data                           | No data      |
| 18  | SBRT1          | 1.0–1.5                                                      | No data                           | No data      |
| 19  | GTR1T          | < 1.0                                                         | 1.67                               | Not matched  |
| 20  | KHR1T4         | < 2.0                                                         | 0.50; 0.55                        | Matched      |
| 21  | PSRT6          | 1.0–1.5                                                      | 0.50; 0.55                        | Matched      |
| 22  | PSRT2          | < 1.0                                                         | 0.70                               | Matched      |
| 23  | KHR1T4         | 1.0–1.5                                                      | No data                           | No data      |
| 24  | KHR1T2         | 1.0–1.5                                                      | No data                           | No data      |
| 25  | KHR1T1         | 0.5–1.0                                                      | 0.43                               | Matched      |
| 26  | JHR1T1         | 1.0–2.0                                                      | 1.86                               | Matched      |
| 27  | JHR1T2         | 0.5–1.0                                                      | 1.30                               | Not matched  |
| 28  | JHR1T3         | 1.0–1.5                                                      | No data                           | No data      |
| 29  | SKRT1          | 1.0–1.5                                                      | No data                           | No data      |
| 30  | BPRT2          | 2.0–3.0                                                      | No data                           | No data      |
| 31  | BPRT3          | 2.0                                                          | 1.60; 1.68                        | Matched      |
| 32  | BPRT1          | 1.5                                                          | No data                           | No data      |
| 33  | SKRT4          | 1.5–2.0                                                      | 1.50                               | Matched      |
| 34  | SKRT2          | 1.0–1.2                                                      | No data                           | No data      |
| 35  | SKRT3          | 1.5–2.0                                                      | 1.88                               | Matched      |
| 36  | JHR1T4         | 1.0–1.5                                                      | No data                           | No data      |
| 37  | BPRT4          | 2.0–3.0                                                      | 1.46                               | Matched      |
| 38  | SDRT2          | 0.5–1.0                                                      | No data                           | No data      |
| 39  | SDRT1          | 1.5–2.0                                                      | No data                           | No data      |
| 40  | PCRT1          | < 2.0                                                         | 3.39; 1.25                        | Not matched  |
| 41  | BGLRT1         | < 2.0                                                         | No data                           | No data      |
| 42  | KBR1T1         | < 1.0                                                         | 0.71                               | Matched      |
| 43  | KDR1T          | < 2.0                                                         | 1.11                               | Matched      |
| 44  | BDRT2          | < 0.5                                                         | No data                           | No data      |
| 45  | BDRT3          | 1.0–1.5                                                      | No data                           | No data      |
| 46  | BDRT4          | 1.0–1.5                                                      | No data                           | No data      |
| 47  | BDRT5          | < 0.5                                                         | No data                           | No data      |
| 48  | SRRT3          | 0.2–0.5                                                      | 1.15                               | Not matched  |
| 49  | SRRT2          | 0.4–1.0                                                      | No data                           | No data      |
| 50  | SRRT3          | < 1.0                                                         | No data                           | No data      |
| 51  | BJRT2          | 2.0–3.5                                                      | No data                           | No data      |
| 52  | SRRT4          | 0.5–0.75                                                      | 0.70                               | Matched      |
| 53  | SRRT5          | 1.0–2.0                                                      | No data                           | No data      |
| 54  | KJRT3          | 1.0                                                          | 1.05                               | Matched      |
| 55  | SDRT3          | < 1.0                                                         | No data                           | No data      |
| 56  | JRRT3          | 0.5–1.0                                                      | 1.13                               | Not matched  |
| 57  | JRRT2          | 1.0–1.2                                                      | 1.50                               | Not matched  |
| 58  | KJRT1          | 1.0–1.5                                                      | 1.11; 1.24                        | Matched      |

Table 3 continues on the next column →

The flood depth data collected through the participatory mapping does not have high accuracy (Table 3) because of bias in converting the flood depth perceptions of respondents into quantitative data. Most of the respondents mentioned the flood depth in their measurements, such as ankle-depth, knee-depth, waist-depth, windowsill-depth or to the roof of the house. The perception of each respondent about the exact size of the measures is different, which causes many differences in the quantitative measurements of flood depth between the information from the respondents and the data obtained in the field. This finding is the same as that of Musungu (2015), who has mentioned this regarding the results from participatory mapping, which are mostly in the form of public perceptions with various measurements that are more qualitative than quantitative data. However, qualitative data obtained from participatory mapping has high accuracy because the respondents are people who have lived in the area for a long time, so they have rich knowledge of the conditions of the area.

The hazard map generated from participatory mapping has high geometric accuracy and precision and high attribute precision regarding more qualitative data. However, because the respondents were mostly given information based on their perceptions and their measurements, there would be many biases that occur during the conversion of their measurements into standard measurement. As a result, the participatory mapping does not have high accuracy, specifically regarding quantitative data.
Participatory mapping in disaster management

The purpose of disaster management is to protect the community from the threat of disasters and ensure the implementation of a planned, integrated, coordinated and comprehensive disaster management. Based on Republic of Indonesia Law No. 24 of 2007, disaster management has the principles of being fast and precise, high-priority, coordinated and integrated, efficient and effective. Thus, the data that are obtained quickly and accurately can play an important role in preventing the occurrence of higher numbers of victims and damages because of disasters. In this context, the data obtained through the participatory mapping process has several advantages over data obtained through other processes.

Flood inundation hazard mapping through participatory mapping has a better level of effectiveness and efficiency when compared with other methods or approaches. The effectiveness and efficiency of a mapping method can be determined by measuring the time and cost involved in its process. The less time and cost required, the more effective and efficient it is. The time and costs required to carry out participatory mapping are relatively small compared with mapping using other approaches that are usually carried out over a large area and require a lot of data and high expertise in its process (Calianno, Ruin & Gourley 2013:1–13; Choi, Kang & Kim 2021:1–10; Spitalar et al. 2014:863–870). The time required for participatory mapping consists of time for preparing a base map and time for conducting participatory mapping of respondents. The time needed to collect data as a base map is relatively short because it only involves collecting secondary data. The amount of time required to conduct a participatory mapping depends on the number of respondents involved. Respondents involved in the study were selected using the purposive sampling technique, so there were not many respondents involved, considering the small area of the research. The small number of respondents means that the flood inundation hazard mapping through participatory mapping did not take much time. Flood inundation hazard mapping through participatory mapping also does not require a high level of expertise, so the process is relatively easy and does not take much time. The costs required in the participatory mapping process only include the cost of transportation to the respondent and preparing a base map for the participatory mapping, which include the cost of printing base maps and purchasing stationery.

Mapping with a participatory mapping approach uses local people’s knowledge as a source of information, so it is suitable for small areas. Mapping in the small area usually has a large scale, which means that it also has detailed information (Butler et al. 1987). Large-scale data have advantages when applied in disaster management, which aims to reduce casualties as much as possible to the individual unit. Moreover, as it directly involves the community or community representatives who have the potential to be exposed to disasters as the source of information, a map derived from participatory mapping has better accuracy for vulnerability assessment in disaster management (Liu et al. 2018:1–23).

The map generated from participatory mapping has high geometric accuracy and precision. It can be seen from the base map utilised and the respondents involved in creating the map. Maps that have high geometric accuracy and precision have insignificant differences in the location from the actual conditions (Shekhar & Xiong 2007). A hazard map that has high geometric accuracy and precision means that the hazard distribution in the location depicted on the map is indeed likely to occur in the actual position. When linked with disaster management, hazard maps with high geometric accuracy and precision will be very beneficial in determining areas prone to disasters, so a great number of victims and losses because of disaster can be reduced.

Apart from its advantages, the hazard maps generated from the participatory mapping do not have high attribute accuracy, specifically regarding the magnitude of the hazard. Furthermore, in case of flood hazards, participatory-based maps have no information about water velocity. Thus, when implemented in disaster management activities, they cannot be used as reference data in terms of quantitative assessments, so they must be supplemented by maps generated through other, more quantitative approaches.

Local leaders’ empowerment for flood disaster

Strengthening, protective and preventive measures are the most important goals for disaster risk issues that require integrated and participatory management. Anticipating the risk of social vulnerability, local leaders become actors or sources of valid information for capacity building through practical participatory actions, that is, disaster mapping. Indonesia has a comprehensive disaster management regulation, but unfortunately there is no preview of future solutions to the turmoil of deadly natural disasters that frequently happen at almost all rural and urban regions and islands in Indonesia. To deal with this nonprovidable regulation, the European Union (EU) has just recently established the Recovery and Resilience Facility, which involved putting into effect a systematic and integrated 36 articles of the 8 chapters of regulation on 12 February 2021, where the recovery and resilience scoreboard in Article 30 put forward its long-term anticipation, impact and management and community involvement and participation for the disaster (The European Parliament and the Council of the EU 2021). In the context of the long-term sustainability of community-centred disaster management, the role of participatory mapping cannot be separated from the guidance of practitioners and scientists of physical geography and social geography to carry out joint and continuous assessments. This study involves several experts (authors themselves) in the study of the application of participatory practical methods for impact analysis and also sociogeographic management in nontechnical or substantive qualitative engagements, which are relatively simple but included the
The study of disaster management from traditional to modern methods and vice versa is not merely a discipline but an expanded discipline along with the systematic resilience of the community, as perceived implicitly by a Mexican social scientist (Solís-Gadea 2006:113–122).

Conclusion

The information on flood inundation obtained from participatory mapping is available on a large scale because it is obtained from a small area. The detailed information from large-scale maps is very relevant to applications in disaster management, which has the principle of reducing casualties to the individual units. Detailed information about flood inundations obtained through participatory mapping does not take much time and cost, so it is very suitable to be applied in disaster management, which generally requires accurate data in a short time. Although the information on flood inundation obtained through participatory mapping has high geometric accuracy, it does not have high accuracy regarding the magnitude of the hazard in a quantitative way, including flood velocity, so supplementary data would be needed to be applied in further assessment for disaster management. In the future, it is recommended that the participatory mapping process should focus on integrative analysis that relies on qualitative data rather than quantitative data of the element at risk. Elements of disaster risk need to be reviewed from a cross-disciplinary researcher’s point of view with a mixed method of qualitative and quantitative and a comprehensive study of social geography, especially the application of mitigation, understanding or education related to disasters and disaster resilience at local, regional and international scales, from and for public (social) safety, by involving stakeholders. This is expected to be a coherent and useful review or input for the progress of the processes of implementing the planning and sustainability of disaster management in Indonesia in the future and future global adjustment norms for disaster.

Importantly, it would be more suitable as an integrative assessment and a malleable approach towards combined participatory approach and community participation in disaster management analyses if a specific physical geography analysis on the element of risk and vulnerability assessment is applied for future studies. This is due to the fact that the respondent involved has the potential to be directly exposed to disasters. Research in the future should be expanded periodically to prevent obsolescence of the meaning and application of the GIS technology and supporting statistics method used.

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The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors’ contributions
S.P. carried out field investigation, data collection, data analysis and drafting of the manuscript. S.P. and J.S. participated in developing the research concepts, supervising and editing the manuscript. L.M. supervised the research analysis and edited the manuscript. A.D.S.d.C. developed the research concepts, supervised the discussion and edited the manuscript.

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Data availability
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References
Aditya, T., 2010, ‘Usability issues in applying participatory mapping for neighborhood infrastructure planning’, Transactions in GIS 14(1), 119–147. https://doi.org/10.1111/j.1467-9671.2010.01206.x
Ahmadalipour, A. & Moradkhani, H., 2010, ‘A data-driven analysis of flash flood hazard, fatalities, and damages over the CONUS during 1996–2017’, Journal of Hydrology 578, 1–13. https://doi.org/10.1016/j.jhydrol.2012.14106
Akbayr, Y.K., 2018, ‘Geometric accuracy test of Google Earth Satellite Imagery with Pleiades-1A for the creation of 1:5,000 scale map (in Indonesian with English summary)’, Undergraduate theses, Institut Teknologi Nasional Malang, Malang, viewed 14 January 2021, from http://eprints.itn.ac.id/1108/.
Bathi, C. & Scannapieca, M., 2006, Data quality: Concepts, methodologies and techniques, Springer Berlin, Heidelberg.
Bizzimana, J.P. & Schilling, M., 2010, ‘Geo-information technology for infrastructural planning’, Transactions in GIS 14(1), 119–147. https://doi.org/10.1111/j.1467-9671.2010.01206.x
Burke, J.T. & McMillin, S.E., 2018, ‘More than place-based: Viewing geography on a continuum and the implications for social work practice’, in R. Devillers & R. Jeansoulin (eds.), Fundamentals of spatial data quality, pp. 31–42, ISTE Ltd., London.
Corbett, J., 2009, Good practices in participatory mapping. A report for International Fund for Agricultural Development, Rome, viewed 26 November 2021, from https://www.participatorymethods.org/sites/participatorymethods.org/files/Good%20Practices%20on%20Participatory%20Mapping.pdf.
Da Costa, A.D.S., 2018, ‘Building community resilience for flood disaster in the West Malakas Subdistrict of Malaka District in the West Timor Island East Nusa Tenggara Province, Indonesia’, A dissertation thesis, Thuringer Universitats- und Landesbibliothek Jena, Friedrich Schiller Universität Jena.
Devillers, R. & Jeansoulin, R., 2006, ‘Spatial data quality: Concepts’, in R. Devillers & R. Jeansoulin (eds.), Fundamentals of spatial data quality, pp. 31–42, ISTE Ltd., London.
Ebrahimpour, Z., Wan, W., Garcia, J.L.V., Cervantes, O. & Hou, L., 2020, ‘Analyzing social-geographic human mobility patterns using large-scale social media data’, ISPRS International Journal of Geo-Information 9(125), 1–33. https://doi.org/10.3390/ijgi902125
Fernandez, A., Najafi, M.R., Durand, M., Mark, B.G., Moritz, M., Jung, H.C. et al., 2016, ‘Testing the skill of numerical hydraulic modeling to simulate spatio-temporal flooding patterns in Logone floodplain, Cameroon’, Journal of Hydrology 539, 265–280. https://doi.org/10.1016/j.jhydrol.2016.05.026
Fulazaky, M.A., 2014, ‘Challenges of integrated water resources management in Indonesia’, Water 6(7), 2000–2020. https://doi.org/10.3390/w60702000
Goodchild, M.F., 2007, ‘Citizens as sensors: Web 2.0 and the volunteered geographic information’, GeoFocus (Editorial) 7, 8–10, viewed 26 November 2021, from https://www.geofocus.org/index.php/geofocus/article/download/107/269.
Government of Purworejo Regency, 2008, Purworejo Regency Regional Regulation Number 7 of 2008 concerning procedures for nomination, appointment, inauguration, and dismissal of village apparatus (in Indonesian), Regional Secretariat of Purworejo Regency, Purworejo.
Government of the Republic of Indonesia, 2007, Law Number 24 of 2007 concerning disaster management (in Indonesian), State Secretariat of the Republic of Indonesia, Jakarta.
Gregory, D., 1994, ‘Social theory and human geography’, in D. Gregory, R. Martin & G. Smith (eds.), Human geography, pp. 78–109, Palgrave, London.
Julizarika, A. & Eki, E.K., 2018, ‘ALOS PALSAR DTM vertical accuracy test against DGNSS-altimeter combination measurement (in Indonesian with English summary)’, Jurnal Pengendaraan Jauh 15(1), 11–24. https://doi.org/10.30536/jpjdh2018.v15.i1.a28.
Keck, M. & Saksadapolk, P., 2013, ‘What is social resilience? Lessons learned and ways forward’, Erdkunde 67(1), 5–19. https://doi.org/10.3111/erdkunde.2013.01.02
Kienberger, S., 2014, ‘Participatory mapping of flood hazard risk in Munaimuka District of Búzi, Mozambique’, Journal of Maps 10(2), 269–275. https://doi.org/10.1080/17445647.2014.891265
Koski, C., Rönneberg, M., Kettunen, P., Eliaisen, S., Hansen, H.S. & Oksanen, J., 2021, ‘Utility of collaborative GIS for maritime spatial planning: Design and evaluation of Baltic Explorer’, Transactions in GIS 25(3), 1347–1365. https://doi.org/10.1111/tgis.12732
Liu, W., Dugar, S., McCallum, I., Thapa, G., See, L., Khadka, P. et al., 2018, ‘Integrated participatory and collaborative risk mapping for enhancing disaster resilience’, International Journal of Geo-Information 7(68), 1–23. https://doi.org/10.3390/ijgi7020068
Mehr, E.T.W., 2008, Land use planning for settlements area considering flood and landslide hazards in Bagelen sub-district Purworejo regency Central Java Indonesia, Masters Thesis, Universitas Gadjah Mada, Yogyakarta.
Mei, B., Sudiyakto, Y. & Kingma, N.C., 2009, ‘Land use planning for settlements area in consideration of flood and landslide hazards in Bagelen, Purworejo, Indonesia’, Indonesian Journal of Geography 41(1), 71–91. https://doi.org/10.22146/ijg.2014.1572
Musungu, K., 2015, ‘Assessing spatial data quality of participatory GIS studies: A case study in Cape Town’, paper presented at the Joint International Geoinformation Conference 2015, Kuala Lumpur, 28–30 October.
Obermayer, N.J., 1998, ‘The evolution of public participation in GIS’, Cartography and Geographic Information Science 25(2), 65–66. https://doi.org/10.1559/15230409872854599
Peczeciw, A., Nisteanu-Pincin, M., Brown, G. & Schnitzer, R., 2012, ‘An evaluation of internet versus paper-based methods for public participation geographic information systems (PPGIS)’, Transactions in GIS 16(1), 39–53. https://doi.org/10.1111/j.1467-9671.2011.01287.x
Purwatiningsih, S., 2020, ‘Flood mitigation strategies in agropolitan area of Bagelen Sub-district Purworejo Regency in Indonesian with English summary’, Masters thesis, Universitas Gadjah Mada, Yogyakarta.
Purworejo Regency Statistical Center Agency, 2019, Bagelen Sub-District in figures, 2019 (in Indonesian), Purworejo Regency Statistical Center Agency, Purworejo.
Purworejo Regency Statisticstal Center Agency, 2019, Bagelen Sub-District in figures, 2019 (in Indonesian), Purworejo Regency Statistical Center Agency, Purworejo.
Srivastave, S., Lesage, N. & Libourel, T., 2006, ‘Quality components, standards, and metadata’, in R. Devillers & R. Jeansoulin (eds.), Fundamentals of spatial data quality, pp. 179–185, ISTE Ltd., London.
Shekar, S. & Xiong, H., 2007, Encyclopedia of GIS, Springer, New York, NY.
Shrestha, S., Imbulana, N., Piman, T., Chonwattana, S., Ninsawat, S. & Babur, M., 2020, ‘Multi-modelling approach to the assessment of climate change impacts on hydrology and river morphology in the Chindwin River Basin, Myanmar’, CATENA 188, 1–17. https://doi.org/10.1016/j.catena.2020.104664
Singh, B.K., 2014, ‘Flood hazard mapping with participatory GIS: The case of Gorakhpur’, Environment and Urbanisation ASIA 5(1), 161–173. https://doi.org/10.1177/1979754215514256
Singh, R.K., Villuri, V.G.K., Pasupuleti, S. & Nune, R., 2020, ‘Hydrodynamic modeling for identifying flood vulnerability zones in lower Damodar river of eastern India’, Ain Shams Engineering Journal 11(4), 1035–1046. https://doi.org/10.1016/j.asej.2020.01.011

Solis-Gadea, H.R., 2005, ‘Introduction: The new sociological imagination: Facing the challenges of a new millennium’, International Journal of Politics, Culture, and Society 18(3/4), 113–122. https://doi.org/10.1007/s10767-006-9008-7

Spitalar, M., Gourley, J.J., Lutoff, C., Kirstetter, P., Brilly, M. & Carr, N., 2014, ‘Analysis of flash flood parameters and human impacts in the US from 2006 to 2012’, Journal of Hydrology 519, 863–870. https://doi.org/10.1016/j.jhydrol.2014.07.004

Sudaryatno, S., Awanda, D. & Pratiwi, S.E., 2017, ‘Participatory mapping for flood disaster zoning based on world view-2 data in Long Beluah, North Kalimantan Province’, in IOP conference series: Earth and environmental science, vol. 98, pp. 1–8, IOP Publishing, Bristol. https://doi.org/10.1088/1755-1315/98/1/012011

Sy, B., Frischknecht, C., Dao, H., Giuliani, G., Consuegra, D., Wage, S. et al., 2016, ‘Participatory approach for flood risk assessment: The case of Yumbeul Nord (YN), Dakar, Senegal’, in D. Proverbs, S. Mambretti & C.A. Brebbia (eds.), Urban water systems & floods, pp. 331–342, WIT Press, Venice.

Thapa, S., Shrestha, A., Lamicchane, S., Adhikari, R. & Gautam, D., 2020, ‘Catchment-scale flood hazard mapping and flood vulnerability analysis of residential buildings: The case of Khando River in eastern Nepal’, Journal of Hydrology: Regional Studies 30, 1–12. https://doi.org/10.1016/j.jhyr.2020.100704

The European Parliament and The Council of The European Union, 2021, Establishing recovery and resilience facility, A Printed Regulation Document Number I 57-17-75, Office Journal of European Union, Strasbourg, France.

Tu, T., Erkan, A., Kavvas, M.L., Trinh, T., Ishida, K., Nosacka, J. et al., 2020, ‘Coupling hydroclimate-hydraulic-sedimentation models to estimate flood inundation and sediment transport during extreme flood events under a changing climate’, Science of the Total Environment 740, 1–13. https://doi.org/10.1016/j.scitotenv.2020.140117

Unduche, F., Tolossa, H., Serbeta, D. & Zhu, E., 2018, ‘Evaluation of four hydrological models for operational flood forecasting in a Canadian Prairie watershed’, Hydrological Sciences Journal 63(8), 1133–1149. https://doi.org/10.1080/02626667.2018.1474219

Van Den Bout, B. & Jetten, V., 2020, ‘Catchment-scale hydrology simulations using inter-variable multi-parameter terrain descriptions’, Journal of Hydrology 589, 1–13. https://doi.org/10.1016/j.jhydrol.2020.125118