A LOW-COST DRONE MAPPING AND SIMPLE PARTICIPATORY GIS TO SUPPORT THE URBAN FLOOD MODELLING

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ABSTRACT:

Obtaining the micro topographic characteristic of river has a decisive role in urban flood mapping and modelling. However, the approachability of high resolution and detail river morphography and micro relief have been often difficult. Furthermore, the variation of spatial and temporal of observation coverage have been often challenging to make the study more low-cost and effective. Nowadays, the advanced of remote sensing technologies can outgrow many of these limitations. the recent development of remote sensing based on small format unmanned drone is capable to produces detail scale of topographic data of the study area. The drone technology is actually a simple system, relatively cheap, effective and well-timed technique in generating high resolution aerial photographs of study area. The objectives of this research were to generate detail land cover and digital elevation by using low-cost drone mapping, also to obtain the historical flood inundation information from local people to support the urban flood mapping in study area. By combining the flood inundation data which was obtained from the participatory GIS process and detail landcover condition, the distribution of flood susceptibility area can be obtained. Further, this data can be used to generate the flood model which is essential for planning, monitoring and controlling the flood in urban area. The results showed that highest flood inundation was 1.7 meter. The most susceptible areas were located between Sungai Pepe and Sungai Kali Gajah Putih especially in ward 1, 2, and 3. Ward 1 is dominated by dense settlement area which is identic to slump. The ward 2 and 3 is dominated by the medium settlement with some agricultural area in between. Furthermore, the risk reduction effort needs to be focused on these wards to reduce the damage and loss when the flood occurs again in study area, by conducting several mitigation programs such as increase the people capacity, establish the evacuation route, and educate the local people.

***Key-words**: Drone mapping, Structure from Motion, Urban flood, Simple participatory GIS.*

1. INTRODUCTION

Urban flood can potentially disturb cities and lead to a major impact both on people and economic. The impact is often amplified by the climate change effect (Hammond et al., 2013) or worse situation such as current pandemic situation of covid-19 (Tripathy et al., 2021). Sufficient preparedness level and adequate disaster management are needed to reduce the risk and loss during the disaster. During the disaster, the evacuation process is one of the critical aspects to minimize the loss of lives (Na et al., 2012). Preparing the evacuation plan is before the flood occurrence is very important and need to involve various criteria including hazard analysis, distribution of inundation area (extent and depth of inundation), accessibility and often social aspect (vulnerability).

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Disaster and risk management of flood can be divided into two major groups; first, the flood hazard and risk analysis or assessment and second, the mitigation aspect. The main purpose of the hazard and risk analysis is to find out where the high flood risk location and where the mitigation actions are mandatory needed. Thus, the core of risk mitigation which means to construct, evaluate, and establish the parameter to reduce the risk in particular area is a comprehensive flood risk analysis and assessment (Meyer et al., 2009).

In term of flood risk analysis and assessment, at least two components must be determined before, i.e., hazard and vulnerability. Hazard talked more about physical characteristic and several aspects of actual flooding such as flood extent and depth of inundation). Vulnerability aspect more focused on the exposure of people, land use type, and various element at risk that might be impacted during the flood event (Schanze et al., 2006; Apel et al., 2009). Landuse and landcover data plays the important role in flood hazard and risk reduction. With this data the accurate damage and loss prediction can be obtained, moreover the evacuation planning can be established precisely. In term of the complexity of the analysis, both hazard and vulnerability assessment have various level of complexity depend on their spatial scale. The detailed analysis should be applied in local spatial scale, meanwhile the less detailed analysis can be applied in regional scale.

Tehrany et al. (2013); Kia et al. (2011); Kuzakis et al. (2015) stated that the flood analysis either at regional or local spatial scale need to identify the location of flood prone area in order to provide early warning system, quick response facilitate, and reduce the impact of potential flood. In general, the prone area of flood can be revealed through several method. Liu et al., 2003 and Forte et al. (2005) generated flood hazard map by super-imposed the geological characteristic and hydrological information in GIS. Furthermore, Dewan et al. (2007) construct the flood inundation map by adding the analysis on the historical data of major flood event in 1998. Multi-Criteria analysis on GIS platform are often used to generate flood hazard zonation. The physical parameters such as elevation, geological and soil characteristic, land use and land cover, hydrological aspect, flood historical data and distance from the river were analysed together by using spatial multicriteria evaluation in GIS platform. The level of important of each parameter were defined clearly on this analysis (Fernandez and luts, 2010; Wang et al., 2010; Kourgialas and Karatzas, 2011; Tehrany 2014).

At the local scale, the accuracy of flood hazard zonation especially the extend of flood, is determined by the quality of input data such orthophoto, DEM and hydrological data (Moore et al., 1991). Nowadays, the advanced development of remote sensing technology, the unmanned aerial vehicle (UAV) has gradually replaced the airborne sensing using the manned aero plane. The flexibility, effectivity, relatively rapid return period, and high-resolution results made UAV more popular than the conventional airborne sensing (Saputra, et al., 2019). On the other hand, the community-based flood mapping also very important in disaster risk reduction program since difficult to find the satellite image which recorded the flood events (Joy, J., et al., 2019). Simple participatory GIS, the extend of flood can be obtained effectively by extracting information from people who live in impacted area.

The objective of this research is to bring the low-cost mapping to support the flood hazard assessment. The integrated approach between drone mapping and participatory GIS can provide the detail data of land use-land cover and the extend of historical flood event which is very important for mitigation plan.

2. STUDY AREA

The study area is Sumber Village which part of the famous watershed in Central Java, i.e., Sumber is located in the middle part of Bengawan Solo Watershed. Gajah Putih and Pepe River are tributary of Bengawan Solo River which often drown some part of Sumber Village in rainy season. In general, Sumber Village lies in the temperate climate zone with the average annual rainfall of 800 mm. From the administrative point of view, Sumber village belongs to Banjarsari District, Surakarta City, Central Java, Indonesia. The situation of the study area can be seen in **Fig. 1** below.

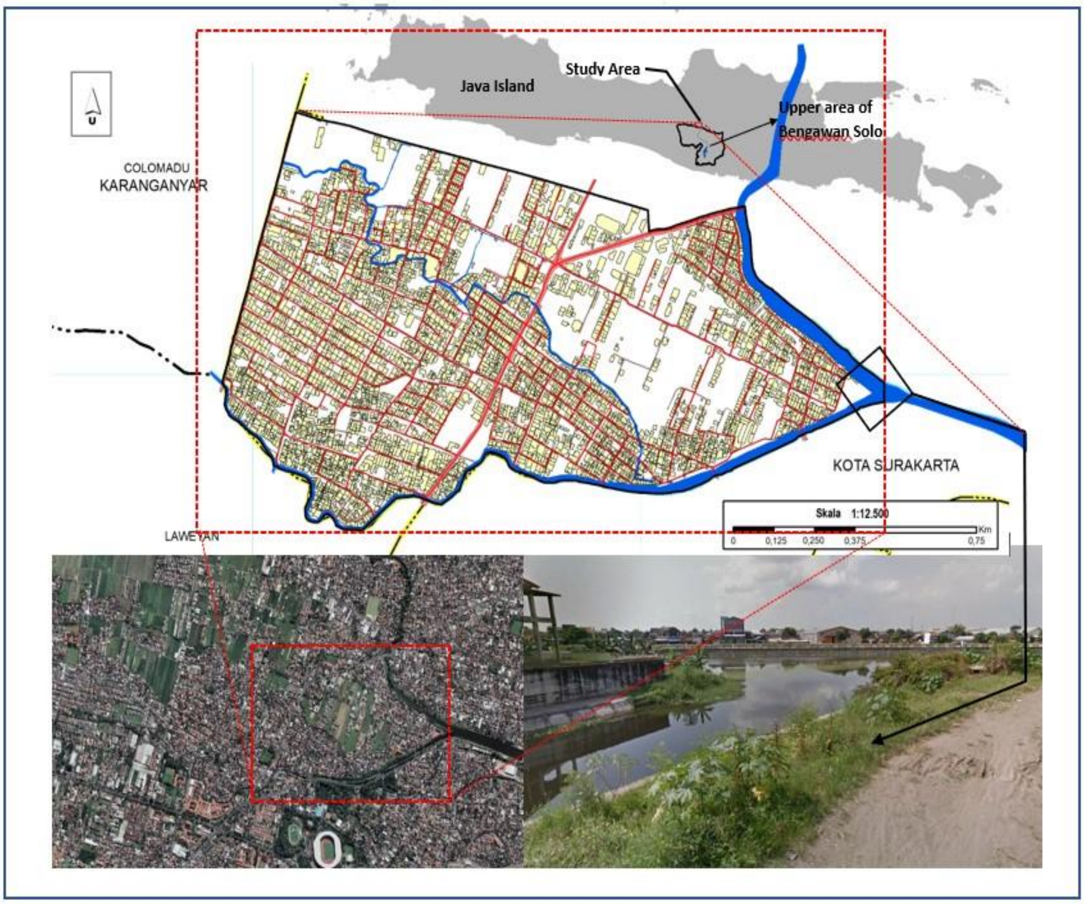

Fig. 1. Study area (above), The orthophoto (left) and the existing condition of the area near the river (Right).

3. METHOD

Given the purpose of the paper, the methods consisted two stages. The first stage was to generate the detail landcover data through the drone mapping. The second stage was to conduct the simple participatory GIS to reveal the extend of the historical flood and the depth of inundation in impacted area.

3.1. Landcover data extraction

Since the high-resolution satellite imagery was not available freely in study area, the drone mapping technique was used to extract the recent and detail landcover in study area. Three main steps need to be conducted such as 1) Data acquisition; 2) Orthophoto process, and 3) Interpretation. Before the drone mapping were implemented, the study area was defined into smaller block with the total area at least 3 hectare and not more than 5 Ha. There is no rule on how to divide the block. The block division was implemented to reduce the risk of loss connected between the drone and controller. The block was established by considering the road at local level and the natural object for instance river. We used the commercial drone of phantom series to conduct the drone mapping in the field. The specification of drone can be seen in **Table 1** below.

Table 1.

The specification of Phantom pro 4 obsidian.

No	Specification	Characteristics
1	Weight (including battery and 4 propellers)	1,375 gram
2	The maximum flight velocity	S-Mode (*Sport mode*): 72 km/ hour A-Mode (*Attitude mode*): 58 km/ hour P-Mode (*Positioning mode*): 50 km/ hour
3	Flight duration (1 battery)	30 minutes
4	Navigation system	GPS/GLONASS
5	Visual record system	*forward, backward,* dan *downward* record system
6	Obstacle sensors	Front and back sensors Infrared sensor in left and right wings
7	Camera	1" CMOS,
8	Wind resistance	Max 10 m/s
9	Operational temperature	0-40^{0}C
10	Photo format	JPEG, DNG (RAW), JPEG+DNG
11	Video format	MP4/MOV (AVC/H.264; HEVC/H.265)
12	Battery	LiPo4S
13	*Charger*	Voltage: 17.4; power: 100W
14	Operational frequency	2.4 GHz/ 5.8 GHz
15	Maximum transmission coverage	4.3 mi (6.9 km)

Source: DJI Forum, 2019.

The orthophoto was generated from the mosaicking process of drone photograph by using Agisoft Photoscan Pro. First the software will align the stereoscopic images. Second, the software will generate the sparse point cloud and dense cloud. The sparse and dense cloud represent the particular point in several photographs which has the same pixel value. The mesh, texture, and orthophoto can be obtained after generating the sparse dan dense. Detail the workflow of drone can be seen in **Fig. 2.**

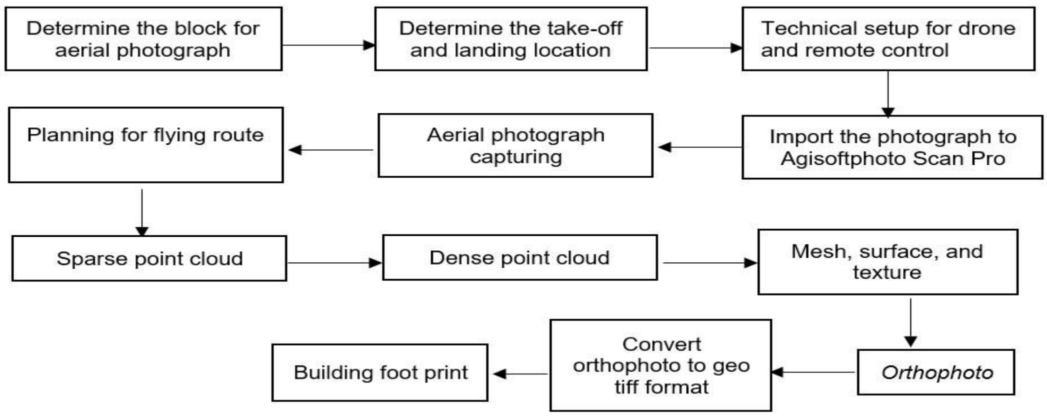

Fig. 2. Research Workflow (landcover extraction).

3.2. Participatory mapping.

Since lack of satellite imagery that recorded on disaster event, the best method to extract the flood extend and inundation depth is to ask the people who live in affected area. Post-flood survey is very important in term of flood hazard analysis. We can get the accurate information about the extent of the flood with relatively simple and effective way. The purposive sampling was used to choose the respondent. We chose the key person live near the river around 250-500 m. We assumed the people who live near the river have better knowledge on flood historical event in this area. The design sample of respondent can be seen in **Fig. 3**.

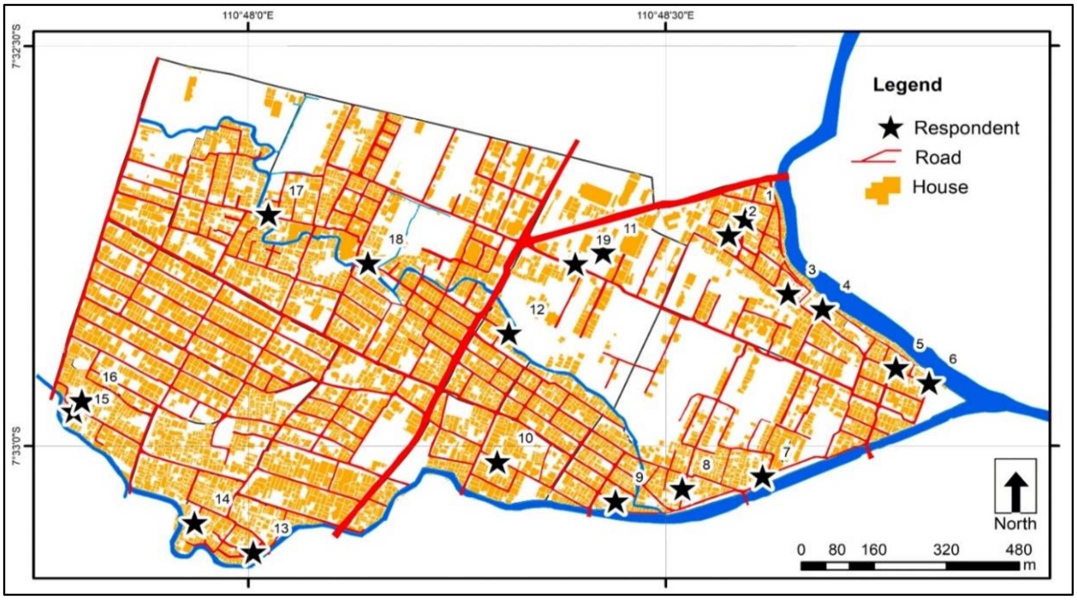

Fig. 3. The respondent distribution.

4. RESULTS

4.1. Block division

Sumber Village is divided into 46 photograph blocks, each of which is approximately 2 to 3 Ha in size. As stated in the introduction, the size of a block photograph plays no specific role. However, due to the radio signal transmission between the aircraft (drone) and the remote control, and for safety reasons, the size of the block photograph was set at least 2 ha and up to 5 ha. When we set up the block photograph more than 5 ha, we frequently experience radio signal transmission loss (drone-remote control is disconnected). When the signal is lost, the drone will automatically hover and return to the take-off position (as default setting in Phantom pro 4 obsidian). As a result, not all photographs will be taken, and the re-launch and image capture process will have to be repeated. The division of block can be seen in the **Fig. 4**. Based on field experience, two flight parameters that are appropriate for conducting drone mapping in urban areas are as follows: 1) the suggested flight elevation is 50-70 m above sea level. If the drone mapping is done at less than 50 meters of elevation, it will take longer, produce more high-resolution images, and pose a greater risk. If the flight elevation is greater than 100 meters, the resulting orthophoto will have less detail and will be more difficult to interpret visually. Furthermore, flights above 100 m can disrupt commercial flights, particularly in the vicinity of the airport. 2) The side-lap and front-lap (overlapping areas) must be determined to be approximately 65 and 75 percent, respectively. The higher the value of front-lap and side-lap in the flight parameter, the more images will be obtained and the longer the drone will operate. In addition, the image mosaicking process will take longer time because the greater the front-lap and side-lap, the greater the number of photos. The flight parameter that needs to be determined before the drone mapping process can be seen in **Table 2** below.

Table 2.

Flight parameter that very important to be set before flight mission.

No	Flight Parameter	Suggestion
1	Flight Altitude	75-100 m
2	Obstacle Avoidance	On
3	Area	2-5 Ha
4	Sidelap	65%
5	Frontlap	75%
6	Take off position	Centre area
7	Take off condition	No obstacle

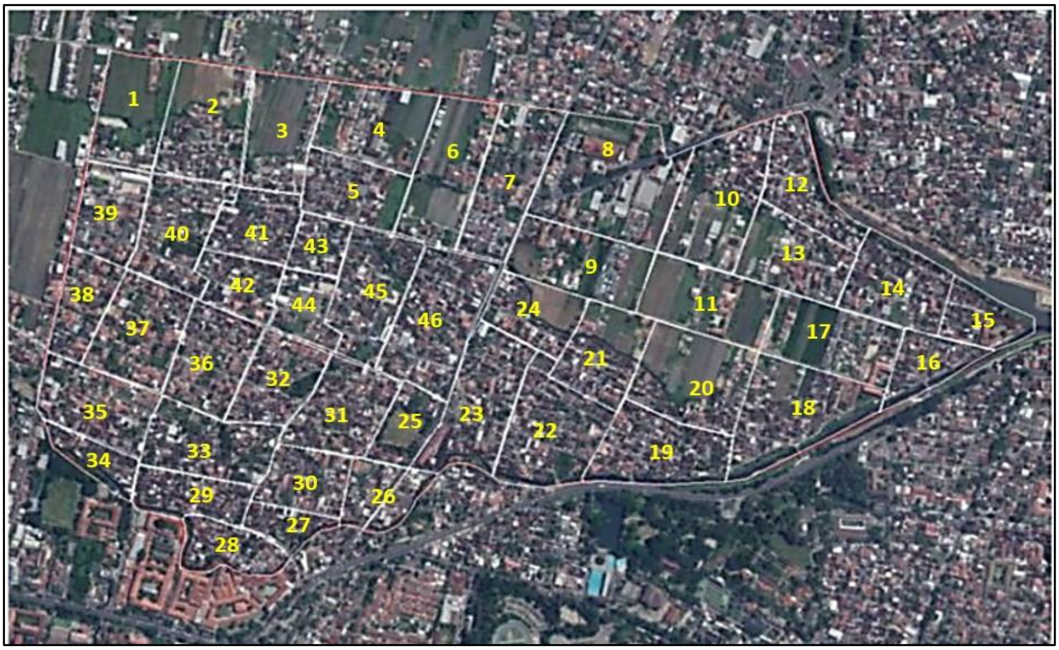

Fig. 4. Block plan of drone mapping.

4.2. Orthophoto

Orthophoto of every single block was generated through several steps (**Fig. 3**). The orthophoto generation starts with the alignment process of photograph. The time required on alignment process differs of every block. It depends on the size of block and the number of photographs. By using the photogrammetry software, the photo taken by drone will align automatically based on the location of camera position. For the size area of 2-3 Ha with the 70 flying altitudes will produce around 30-35 photographs. The time requirement for one alignment process is around 4 minutes 48 seconds. The illustration of alignment process and the result are provided **in Fig. 5**.

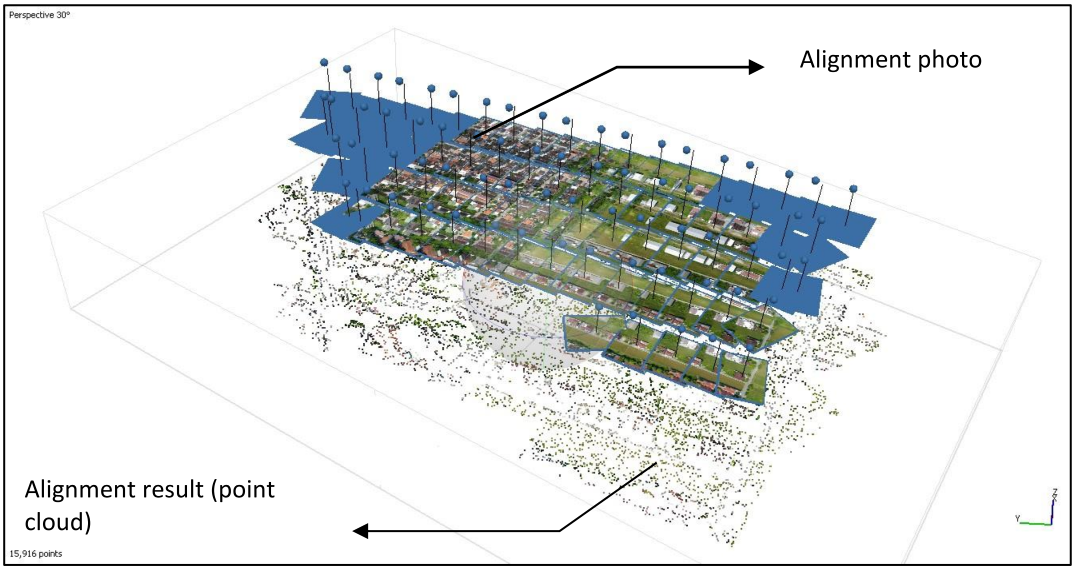

Fig. 5. Illustration of alignment photo and point cloud generation.

Further, the sparse point cloud (the results of align photo) will be derived into dense point cloud. The software tries to extrapolate the sparse point cloud into much more point which is appear in at least two scenes of photos. For instance, in Figure 5 above, the number of points of the area observed are 15,916 points, in the dense point cloud, the number of points increase become, 14,157,740 points. Although, the point is much more than previous process, the dens point cloud generation took faster, i.e. 2 minutes 21 seconds. The example of dense point cloud of block number 8 can be seen in **Fig. 6**.

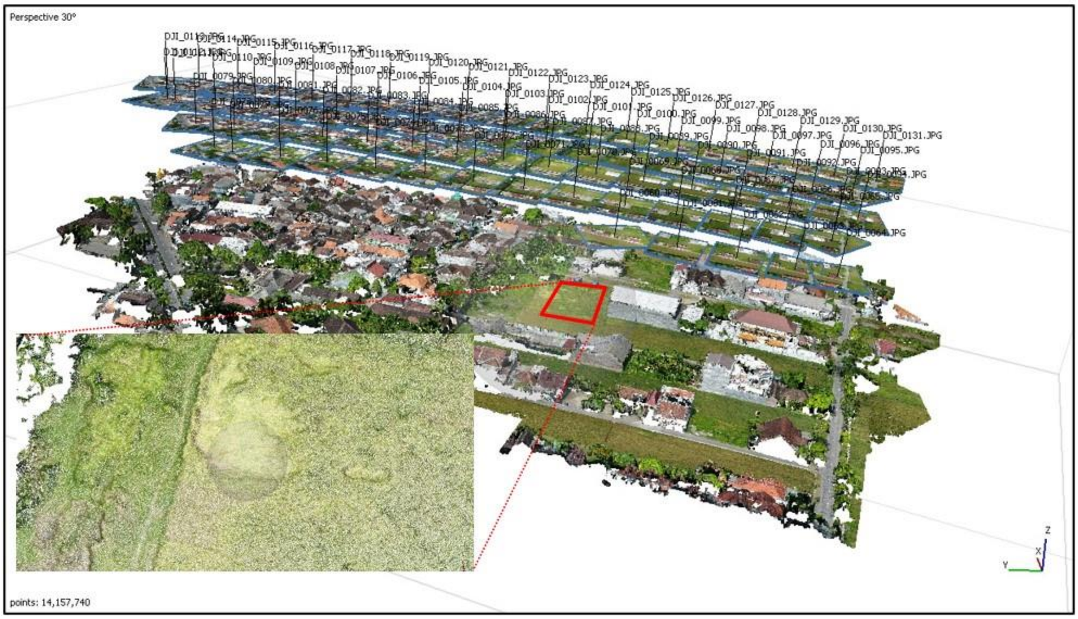

Fig. 6. The dense cloud of block 8.

The last step before DSM extraction is to generate the surface texture. This process was executed by using the dense cloud from the previous process. By using orthophoto mode, mosaic blending mode, and medium quality this process (around 14 million points) can be finished in 1 minutes 42 seconds and produced 308,057 faces and 154,627 vertices. The orthophoto was generated by exporting the textured surface to orthophoto. The example of textured surface of block 8 can be seen in **Fig. 7**, meanwhile the orthophoto can be seen in **Fig. 8**.

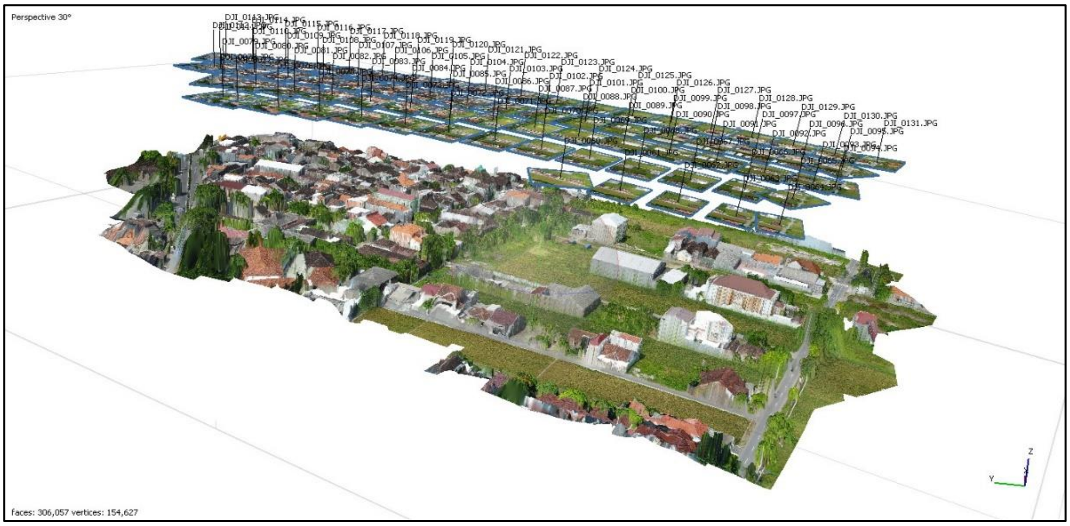

Fig. 7. The textured surface of block 8.

Fig. 8. The orthophoto of block 8.

4.3. DSM Generation

The DSM was generated after applied the point classification to the dense cloud. The point classification follows automatically in agisoft photoscan pro classification. There were several classifications such as ground, high vegetation, building, road surface, cars and man-made object. For example, the north part of block 8 has minimum elevation of DSM around 133 m and the highest point around 151 m. Please see **Fig. 9** to check out the DSM of the north part of block 8.

Fig. 9. The DSM and orthophoto of the north part block 8.

5. DISCUSSION

Based on the orthophoto results, the landcover especially the built area can be clearly distinguished. By using the visual interpretation technique land cover in study area can be divided into several major group such as building (House), agricultural vegetation, non-agricultural vegetation, bare land, water body, and road. Those all object can be identified by analyses the colour/tone element and other element such as shape, pattern, association, shadow, and size. The key interpretation of several object can be seen in **Table 3** below.

Table 3.

The example of object identification.

Object	Color/ Tone	shape	pattern	Shadow
Agricultural land	Green to light brown	rectangle	Clustered	non
Building	Brown, green, white	rectangle	Clustered	yes
Water Body	Blue	longwise	longwise	no
Road	Dark gray	longwise	longwise	yes

The building map was extracted from the interpretation results by observing the existence of shadow. Some objects have the similar color with the rooftop of the building, however if there are no shadows around the object then the object was considered as bare land or sports field. The results of the building can be seen in **Fig. 10**, meanwhile the results of orthophoto, landcover and the building map are provided in the **Fig. 11**.

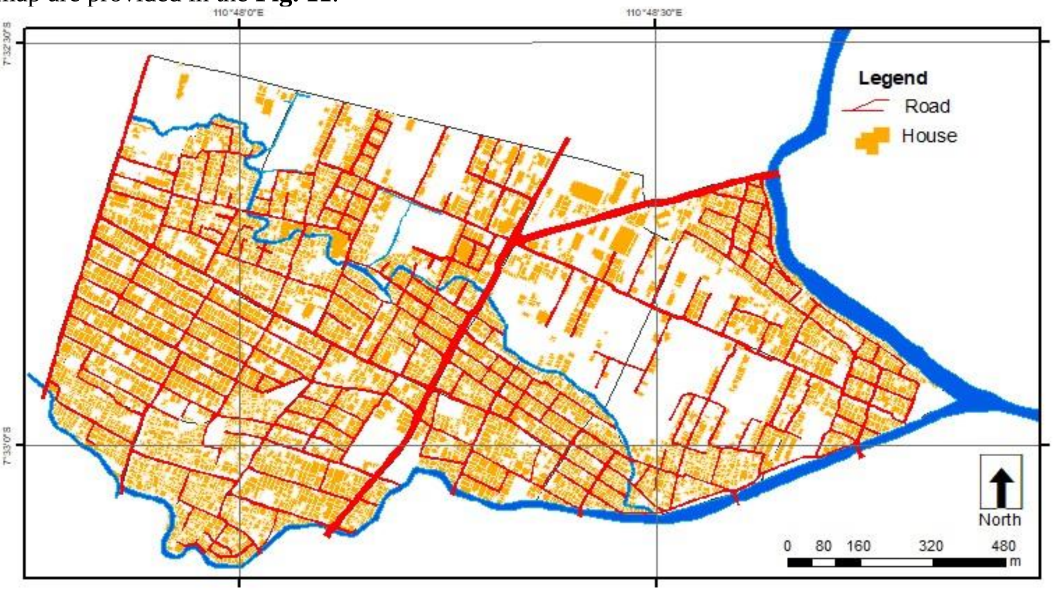

Fig. 10. Building footprint of study area.

Based on the participatory mapping, the worse flood in study area occurred in 2015 with the highest water raise of 170 cm. the depth of inundation on metric scale was generated from the conversion of relative scale by using body parts benchmarking technique. Thus, if the respondent said that the last flood 2015 inundated the house until at least as high as neck of adults, it means the depth of inundation is around 150. This conversion technique used the average height of Indonesian adults which is 162.6 cm.

Based on the participatory mapping from several keyperson, it can be seen that the lowest inundation depth is 10 cm or as high as an adult's ankle. The most prone area to flood is located in the eastern part of Sumber Village. This prone area covers at least three *RT* (the lowest administrative units) or neighborhood, i.e., RT 1-3.

Fig. 11. Orthophoto, drone image of block 1-2, and landuse map of study area.

The average flood depth in those areas was 1.5-1.7 m. in term of geomorphology, this area can be classified as flood plain which has fertile and thick soil. However, during the rainy season this area is often inundated by the water as the debit of th river increase. Furthermore, this area is located in ‘hook” location between Kali Gadjah Putih and Pepe River which can amplify the impact of flood and increase the depth of flood. The distribution of flood inundation Is provided in the **Fig. 12** below.

The advanced technology nowadays allowed us to extract the topographic data by the relatively simple and low-cost method. Drone mapping is able to generate local DSM and DEM or even ectract land use and landcover data in local scale with has flexibility of temporal resolution and rapid acquisition. By combining with the information of depth from the local people by using simple participatory mapping, the model of flood inundation can be generated and can be used for further contingency plan or mitigation. Based on the results, the eastern part of Sumber village has the deepest flood around 1,7 m. with this high It will be inundated everything including road and paddy field except the building. Further to reduce the impact of flood the local government need to make collaboration plan to establish the evacuation planning in the eastern part of Sumber Village. This is important as the most crucial aspect to mitigate the flood. The local government need to plan precisely which neighborhood that need help first during the flood disaster.

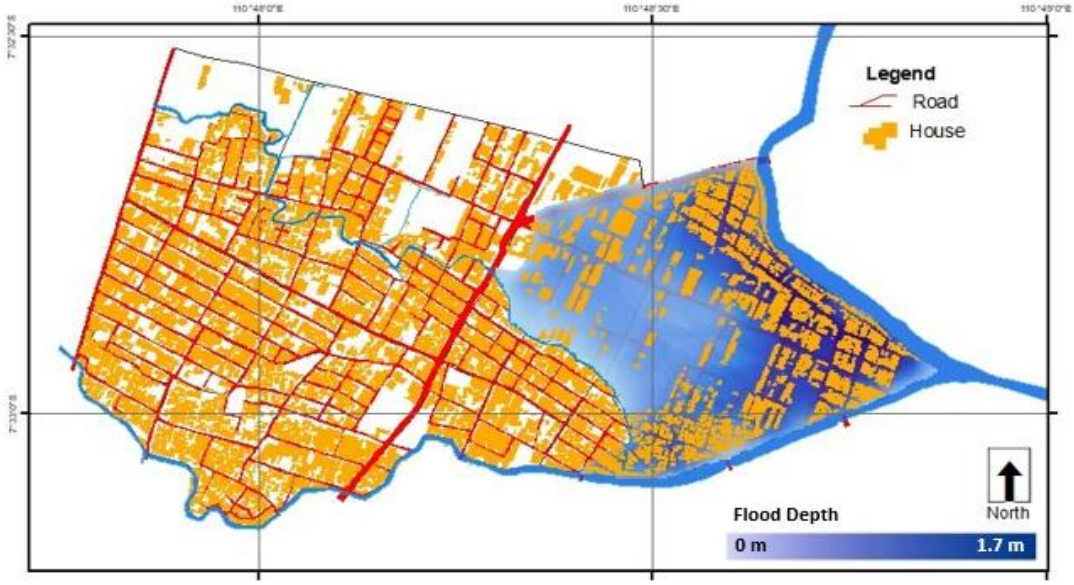

Fig. 12. The flood inundation distribution.

6. CONCLUSION

The most prone area to flood is located in the eastern part of study area especially in *RT* 1-3. The average depth of inundation in this area around 1.5-1.7 m. Based on the result, it is revealed that the integrated method between the drone mapping and participatory GIS can be an alternative method to support the flood mitigation planning at local level.

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