UNIVERSITAS GADJAH MADA

JASA TIRTA I
JALAN SURABAYA 2A, MALANG

MSD NetWork

IAHR AIRH
International Association for Hydro-Environment Engineering and Research

Supported by
Spain Water and IWHR, China

IAHR-APD 2018
Yogyakarta, Indonesia

PROCEEDINGS

21st IAHR-APD Congress

International Association for Hydro-Environment Engineering and Research (IAHR)
Asia Pacific Division (APD)

Multi-perspective Water for Sustainable Development

Volume 2

- Water Resources
- Hydroinformatics
- Water-related Disaster Risk Reduction
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FOREWORDS FROM CHAIRMAN OF THE LOCAL ORGANIZING COMMITTEE

Dear Readers,

Universitas Gadjah Mada was honored to host the 21st Congress of International Association for Hydro-Environment Engineering and Research-Asia Pacific Division (IAHR-APD) on 2-5 September 2018 in Yogyakarta which was co-hosted by PT. Jasa Tirta I (Jasa Tirta I Public Corporation) and Multimodal Sediment Disaster Network (MSD-Network). The Congress brought up the theme "Multi-perspective Water for Sustainable Development". This phrase was adopted as the main theme of the Congress to maintain awareness of the stakeholders that water should be valued from various viewpoints namely technical, socio-economic, cultural and environmental viewpoints which integrate all efforts on water resources-related development to contribute to people's welfare.

The 21st Congress of IAHR-APD accommodated the 6th AUN/SEED-Net Regional Conference on Natural Disaster (RCND 2018) which was mostly relevant to water-related natural disasters to be part of the Congress. The joint congress was aimed at introducing the IAHR-APD organization to even wider areas of hydro-environment engineers and scientists as well as strengthening cooperation with similar organizations.

The Congress has successfully encouraged the interactions among researchers, industries, and communities, on the dissemination of water-related research achievements and ideas that paves the way for sustainable water and environment-related development. The local organizing committee especially appreciates all of the staff of the IAHR and IAHR-APD for their endless and excellent support to the congress.

The cooperation and support of Universitas Katolik Parahyangan, Sekolah Tinggi Teknik Nasional Yogyakarta, Universitas Kristen Duta Wacana are also highly appreciated. We would like to thank all of the sponsors and participants for their contributions to make the Congress fruitful and memorable. Our special thanks go to the reviewers of the papers and the editors of the proceedings without whom the publication of such excellent quality proceedings would not have been possible. We hope that this proceedings will furnish the readers with excellent references and stimulate further studies and researches in the related areas.

Thank you very much and God bless you all.

Radianta Triatmadja

21st IAHR-APD 2018 Congress Chair

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FOREWORDS FROM CHAIRMAN OF THE IAHR-APD

It is my great honor and pleasure to say 'Welcome' to all the attendees of the 21st Congress of the International Association for Hydro-Environment Engineering and Research-Asia Pacific Division. The IAHR-APD Congress is the official and most important open forum for all persons, not only the members but also general participants, who are interested in presenting, discussing, and exchanging their knowledge and experiences in hydro-environment areas. Since the first congress was held in Bangkok, Thailand in 1978, this is the 21st, following the previous congress that was held in Colombo, Sri Lanka two years ago with great success in terms of numbers of papers presented and participants. You can see about the past APD congresses at the official website of IAHR-APD http://www.iahrapd.org/Apd/Congress/webinfo/2014/08/1408074914387664.htm.

We, the APD members, have tried to delineate as well as generalize the conference characteristics such as by emphasizing specialty sessions dealing with the water-issues which are especially important and sometimes unique in the Asia and Pacific region such as typhoon, monsoon, and tropic-affected water issues, as well as historical water projects and traditional water technologies in the region. For example, we have special sessions of Historical water projects and traditional water technologies in the Asia-Pacific region, Green infrastructure as disaster risk reduction measure, Ecosystem-based disaster risk reduction for floods and tsunamis, Adapting to climate change using green infrastructure and LID measures, Conceptual ideas to solve problems related to hydro-environment engineering, Volcano and multimodal sediment disaster, Simulation and risk mitigation, and Hydrology-geomorphology links in tropical rivers. At this congress, we are also hosting some international panels with recognized high-ranking officials on the water issues that are of mutual interests in the region.

Among many special sessions that are held at this conference, the session of Historical water projects and traditional water technologies in the Asia-Pacific region, would be worthwhile to introduce more in detail. It has the purpose of giving international professional recognition to the works of: 1) past water projects that contributed or are still contributing to the welfare of the people, and 2) past brilliant water technologies that blossomed once and are still useful in the Asia – Pacific region. The first special session was held in Sri Lanka congress in 2016 with seven presentations from different countries in the region. Those are now in the process of being published in the Journal of Hydro-environment Research (JHER), the official journal of IAHR-APD, as a special issue. This type of special session will continue at every APD congress and a few papers presented at the session will be strictly screened and submitted for a possible publication in JHER along with the ones receiving the best-paper award in the congress.

I strongly believe that this conference should be a very useful and effective forum in which we are able to foster interdisciplinary research and collaboration, rapid dissemination of latest findings, and will provide an opportunity for discussing how novel methods and techniques can be used interchangeably in various fields and application areas of hydro-environment engineering and research especially in the Asia and Pacific region.

Last, but not least, I as the IAHR-APD chair express many thanks to the LOC members including Prof. Radianta Triatmadja, the conference chair, for their full devotions to the preparation and proceedings of the conference for the last two years. I strongly believe that this conference will be one of the most successful events ever in the history of the IAHR-APD activities.

Hyoseop Woo

IAHR-APD Chair

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DEVELOPMENT OF FLOOD INUNDATION MAP USING UAV-BASED DEM ON RESIDENTIAL AREA

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ABSTRACT

This paper presents the hydraulic modeling and simulation to develop flood inundation map in residential areas using high-resolution digital elevation model (DEM) generated by Unmanned Aerial Vehicle (UAV) survey. The research was done at Bukit Sejahtera and Tanjung Rawa residential areas located in Palembang City, South Sumatra Province, Indonesia with total area about 200 ha. The new HEC-RAS 5.0 was used as a hydrodynamic model to simulate the combined one and two-dimensional flow routing based on 5-year return period of flood hydrographs for upstream boundary conditions and the highest tide level for downstream boundary condition. The results show that the UAV survey can produce a high-resolution DEM. The grid size of UAV-based DEM was generated in this study is 0.1x0.1m, so it can be said to have a high spatial resolution. The simulated flood depths compared with measured data show a good trend and corresponding values. However, a more detailed calibration cannot be performed because of the limitation of measurable data. Nevertheless, the results of this study have demonstrated the enormous potential use of UAV in the future to acquire high-resolution elevation data for generating a detailed and accurate flood inundation map. The authors believe that the utilization of UAVs will be more extensive for flood control and management strategies, especially in Indonesia due to its flexibility, reliability and affordable cost. The characteristic of flood depths in the study area is also discussed in this paper.

Keywords: *Flood mapping, hydrodynamic model, GIS, UAV*

1. INTRODUCTION

Flood is natural phenomenon may frequently occur especially in urban areas. The flood inundation could happen due to heavy rainfall and spring tides in lowland areas, i.e., areas that the surface elevation is lower than tide level. Both structural and nonstructural approaches are taken to obtain the optimal solution for the planning of flood control and mitigation. For such purposes, a series of hydrologic and hydraulic analyzes combined with GIS are required to obtain potential flood inundation map that may occur in an area.

The accuracy of flood inundation is highly dependent on the level of accuracy of elevation data used (Haile & Rientjes, 2005; Marks & Bates, 2000). The elevation data, known as digital elevation model (DEM) is a model to represent the appearance of surface topography in three-dimensional format (Ruzgiene et al., 2014). The spatial resolution value can show the accuracy level of DEM. The higher the resolution of DEM, the better accuracy in term of elevation can be achieved and vice versa. The DEM is said to have a high spatial resolution if the grid size is less than 1 m, and high accuracy if the height error is less than 0.05 m (Pichon et al., 2016). Several previous studies have shown that the higher the DEM resolution used, the better the accuracy of the resulting flood map. As an example of a study conducted by Hsu, et al. comparing simulation results of flood inundation within Sanyei drainage area located in southern Tainan City, Taiwan by using light detection and ranging (LiDAR)-based DEM with five different grid sizes, i.e., 1x1m, 5x5m, 10x10m, 20x20m, and 40x40m. The results showed that the coarser of the grid size used, the area of inundation becomes larger where the accuracy of the simulation is reduced. It can be due to the coarser DEM simplifying the topographic information thus affecting the hydraulic characteristics of the simulated area (Hsu et al., 2016). The same results are also

explained in (Brandt & Lim, 2016) and (Haile & Rientjes, 2005) which the inundation area generated by the coarser DEM tends to be overestimated compared to the finer DEM. Furthermore, Hsu et al. (2016) also explained that flood inundation map is the most essential information in the estimation of economic losses so that high-resolution DEM is required to obtain better simulation results. A sufficient number of ground control points (GCPs) is necessary to produce an accurate DEM. Coveney & Roberts (2017) have simulated flood inundation of DEM with varying amounts of GCPs, i.e., 5, 10, 15, 30. 45, and 61 sets. The simulation results showed that the more the number of GCPs, the smaller the elevation error of generated DEM, so the inundation area becomes closer to the observed one. It indicates that a sufficient GCPs number can provide better accuracy for the resulting inundation map (Coveney & Roberts, 2017). However, the high-resolution DEM is usually generated only by technologies such as Interferometric Synthetic Aperture Radar (IFSAR) and LiDAR at prohibitive cost (Coveney & Roberts, 2017; Hashim et al., 2016). It becomes an obstacle especially for developing countries that still rarely or not commonly use LiDAR technology and with limited budgets for flood control studies also (Wedajo, 2017). Therefore, it is necessary to have technology that can produce DEM with high spatial resolution but affordable cost so that it can be applied widely for flood control and mitigation works.

The unmanned aerial vehicle (UAV) is a device commonly used for purposes such as photography, monitoring, and remote sensing. Recently, the UAV has been extensively researched for photogrammetry surveys so that it can generate DEM with high spatial resolution and level of accuracy. De Silva et al. (2016) mentioned that spatial resolution of DEM created by UAV survey could be less than 1 m. Pichon et al. (2016) explained that UAV-based DEM could have a high level of accuracy with elevation error less than 0.01 m. The same is also mentioned in (Entwistle & Heritage, 2017). This value is smaller than the height error generated by conventional photogrammetry survey, which is 0.35 m (Hudec, 2011). Even the accuracy of UAV-DEM may have more average minor mistake compared to LiDAR, thus indicating the UAV survey can be more effective than LiDAR (Entwistle & Heritage, 2017). However, the maximum height error of UAV-DEM may go up to 0.55 m (Ruzgiene et al., 2014). The degree of error is highly dependent on flying height, camera characteristics, and the number and accuracy of GCPs (Küng et al., 2011; Ruzgiene et al., 2014; Santise et al., 2014). Jeong et al. (2016) have investigated the level of DEM resolution may be generated from UAV survey. The results showed that UAV survey could produce DEM with high-level spatial resolution up to 0.05 m. Also, the costs incurred for DEM data acquisition using UAV are still affordable compared to other photogrammetry technologies and terrestrial surveys (Madawalagama et al., 2016). It suggests that UAV technology should be used widely for mapping purposes especially in flood inundation mapping (Sze et al., 2015).

This paper deals with the mapping of potential flood inundation through hydrodynamic modeling by using DEM generated by UAV survey. The object of this research are residential areas constitute of lowland influenced by the river tides so often being flooded. This research is expected to contribute in the application of UAV technology widely for the making of flood control strategies and plans, especially in developing countries such as Indonesia, where the technology of LiDAR survey is relatively expensive and still very rarely used.

2. METHOD

The two residential areas as the object of this research are Bukit Sejahtera and Tanjung Rawa residence with total area about 200 ha located in Palembang City, South Sumatra Province, Indonesia (Figure 1). In general, some regions in Palembang are lowland so that the areas may be flooded during spring tides (Putra et al., 2011). The study area has similar characteristic to such regions with a relatively low and flat topography affected the Lambidaro River tides, which is a drainage subsystem that is flowing into Musi River, the largest river in South Sumatera Province. During the rainy season, which is accompanied by spring tides from the river, the residential areas are often flooded. Some previous studies on flooding in Palembang City have been conducted by Al Amin et al. (2017) and Farid et al. (2017) indicating that the residential areas on which this study was located have a moderate level of flood hazard.

In this study, DEM data were collected from photogrammetry survey using commercial UAV type quadcopter, namely DJI Phantom 3 Advanced with flying height set to 100 m from the surface. This flying height is sufficient to produce high-resolution DEM maps (Jeong et al., 2016). This UAV was equipped with 12.4 MP resolution camera, GPS, and altitude sensor. Figure 2 shows the UAV and supporting devices used in this study as well as the process of acquisition data. The control points employed as many as five GCPs connected to GPS RTK. The flight time for single flight mission was about 15 – 20 minutes. The resulting data were in the form of photo mosaics, which were then merged to become a unified orthophoto. The DEM map was generated using an extracted of the dense point cloud. This paper does not focus on the process of data acquisition and processing method from UAV survey. The complete explanations on the UAV types, specifications, the process of acquisition and data processing can be found in excellent detailed in (Madawalagama et al., 2016) and (Ajayi et al., 2017).

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Figure 1. Area of study


Figure 2. The UAV, marker point (GCP) and GPS RTK used in the study and the illustration of the process of acquisition and data processing

The stages of analysis conducted in this study are a hydrologic and hydraulic simulation and flood mapping respectively. The HEC-HMS software was used for hydrologic simulation, which produces flow hydrographs in the Lambidaro subsystem based on the Soil Conservation Service (SCS) rainfall-runoff model. The completed

explanations about the process and results of this simulation can be found in (Al Amin et al., 2015). The flow hydrographs were then set as upstream boundary conditions in the hydraulic simulation. The HEC-RAS 5 was used as for hydraulic flood simulation based on a combination of 1-dimensional and 2-dimensional (1D/2D) flow that completely solved using the Saint-Venant 2D equation (Patel et al., 2017). The downstream boundary condition was the highest tide elevation resulting from tidal forecasting based on measurable data on the Musi River. The simulation results were then integrated with the GIS software so that a flood inundation map was obtained for the study area. Although HEC-RAS 5 is new software, several previous studies as in (Patel et al., 2017) and (Quiroga et al., 2016) have shown that the HEC-RAS 5 successfully simulates flood inundation accurately. It suggests that HEC-RAS 5 can be widely applied, especially in strategies for better flood management and control.

3. RESULTS

3.1 Digital Elevation Model (DEM)

The DEM map generated from the UAV survey for the study area is given in Figure 3. In the figure, the surface elevation shown in the center of the residential area is higher than the surface elevation near the river. It is due to the former landfill for the construction of housing in the residential area. Based on generated DEM from the Figure 3a, when the cross-section is made in detail (Figure 3b), a surface elevation profile is obtained which very clearly illustrates the shape of a building. It shows that the DEM produced by UAV has excellent quality. The resolution of the DEM generated by the UAV for the study area is 0.1 x 0.1 m so it can be said to have a high resolution.

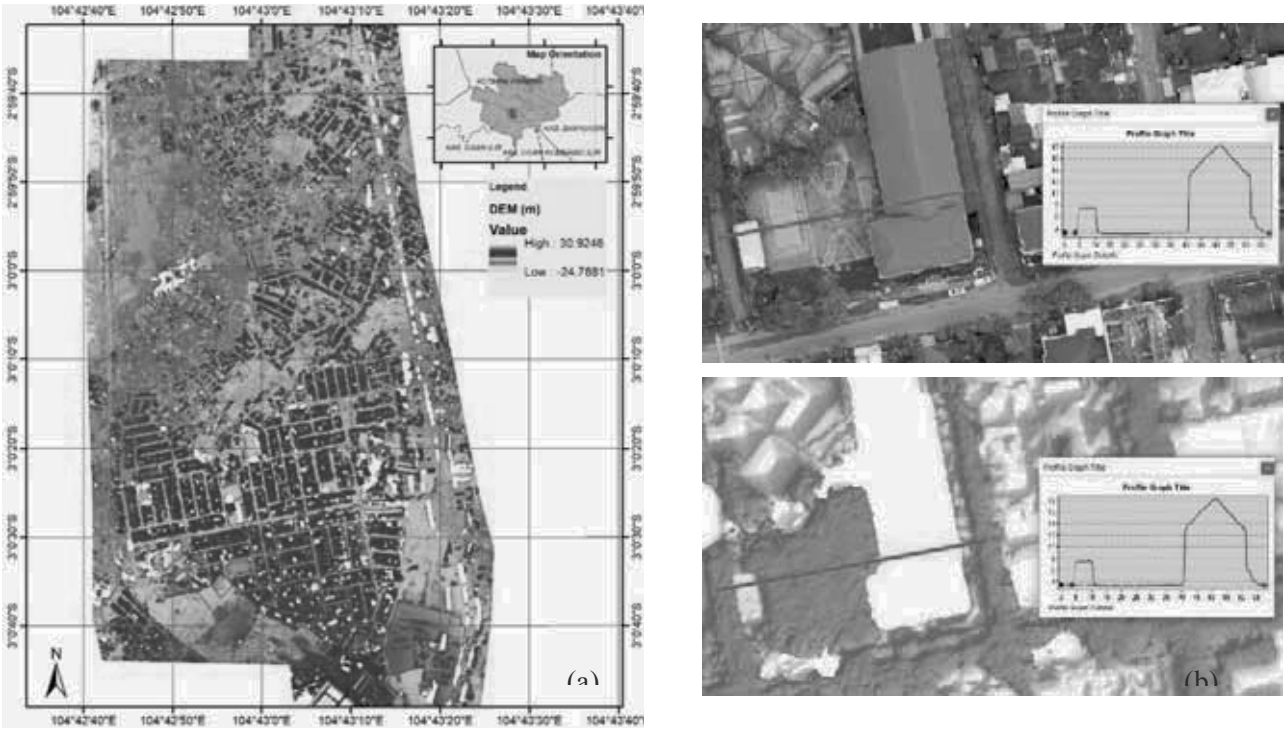

Figure 3. The DEM map of the study area (a), an example of the detailed cross-section to illustrate the shape of the building (b)

3.2 Hydraulic simulation

In this study, the new HEC-RAS 5 was used as a hydrodynamic model to simulate flood inundation with the principle of a combination of 1-dimensional and 2-dimensional flow. The scheme of the geometric model applied to the study area is given in Figure 4a. In the figure, the 1-D domain is represented by stream flows as a function of depth along the channels, whereas the 2-D domain is described by the overland flow of the floodplain surface as a function of depth in the 2D areas. The 1-D flow domain is associated with a 2-D flow domain using lateral structures. The upstream boundary conditions of the channels were the flow hydrographs of a 5-years return period with a peak discharge of 34.4 m^3/s (RS 1890.761), and 22.2 m^3/s (RS 2729.567) resulted from hydrologic simulations using HEC-HMS. For the downstream at RS 204.551, the boundary condition was the highest tide with a level of 3.46 m resulting from tidal forecasting. In the 2DArea geometry model, the surface roughness values for the study area were determined based on the land use that affected overland flow.

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Based on the result of hydraulic simulation given in Figure 4b, it is seen that most of the inundated areas with high flood depth are located near the river, whereas the lower depth occurs for the area further. It is because the surface elevation of the areas near the river is lower than the surface elevation at the center of the residential area. Flood depth map in more detail is given in Figure 5. The picture shows that the depth of inundation in Bukit Sejahtera residence ranges from 0 to 1.5 m, whereas in Tanjung Rawa residence ranges from 0 - 4.25 m. It suggests that the area of Tanjung Rawa residence has the potential to experience higher flood risk compared to Bukit Sejahtera residence. Based on the picture can also be seen that the areas that are very vulnerable to be flooded are directly adjacent to the Lambidaro River.

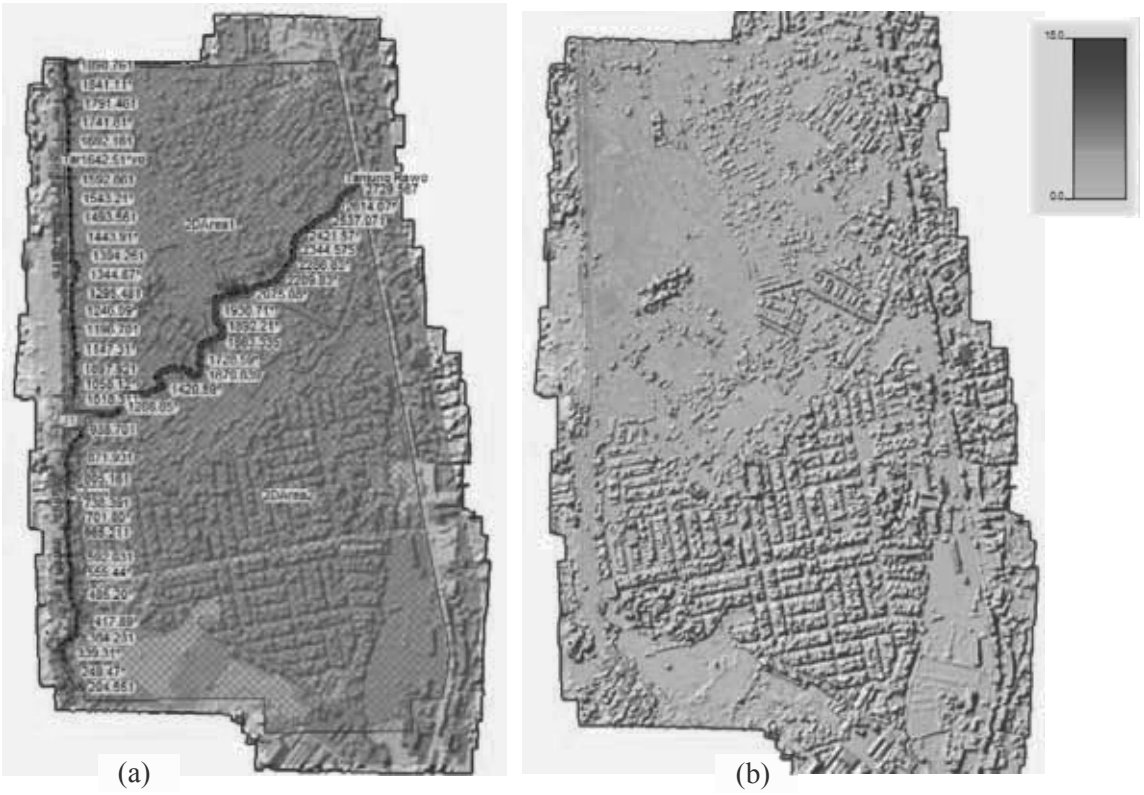

Figure 4. The geometry model for stream channels (1-D domain) and floodplain (2-D domain) in HEC-RAS (a), the simulation result shows flood inundation visualized in RAS Mapper (b)

The calibration of flood simulation result was conducted by comparing the flood depth to the observed data at 41 observed points as shown in Figure 5. Since in the study area the water level recorder was not available, the observed flood depths were taken by interviewing the residents and observing the ex-flood marks on the walls, fences and so on. Although this method does not provide accurate data of the real flood conditions in the study area, the simulation and observation results show that the flood depths and its trend are corresponding each other as given in Figure 6 though with reasonably high errors. It suggests that the simulation result of the flood inundation can be accounted for with satisfactory result.

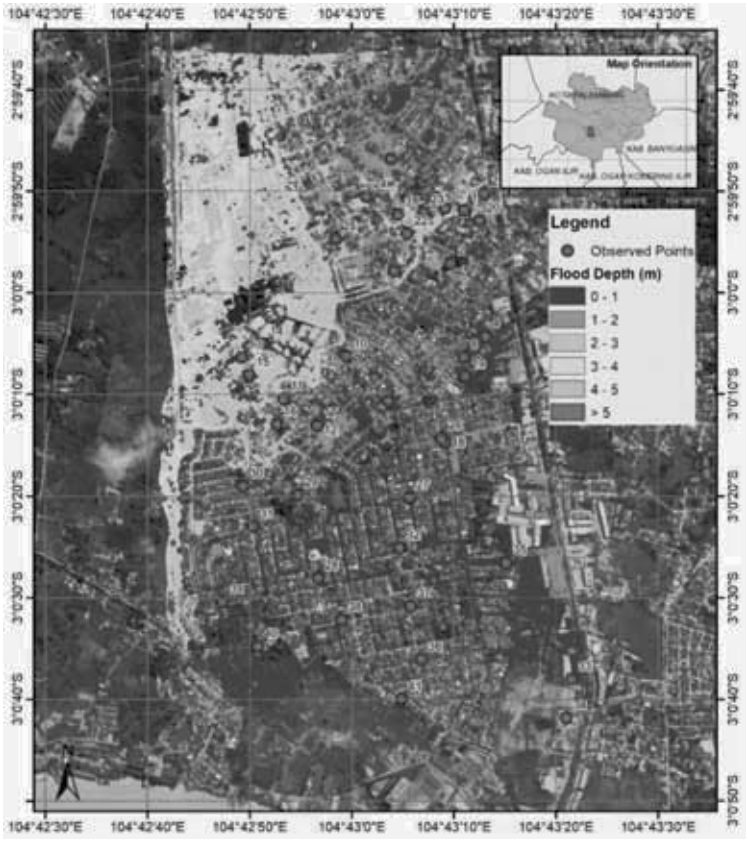

Figure 5. Flood inundation map for the study area, along with 41 observed points

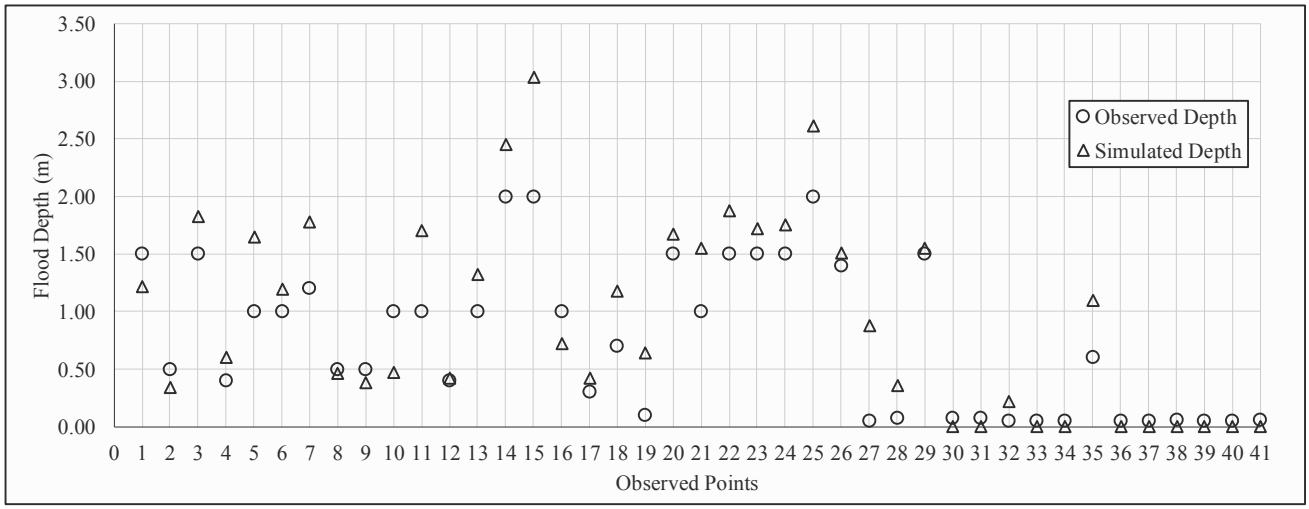

Figure 6. The comparison of simulated and observed flood depths in the study area

4. DISCUSSION

4.1 Findings

The flood as a natural phenomenon that often occurs should be estimated early using a flood inundation map generated from high-resolution DEM. Although LiDAR is currently the best technology to produce such DEM maps, its utilization in developing countries is still insufficient, especially in Indonesia. Also, the costs required for the airborne-LiDAR survey are still prohibitive. It led to the more extensive use of UAVs to produce high-resolution elevation data through photogrammetry surveys. This research has succeeded to create DEM map with high spatial resolution, that is 0.1 x 0.1 m for Bukit Sejahtera and Tanjung Rawa residential area with total area about 200 ha. The DEM map can be used in hydraulic simulation using the combined 1D/2D flow of HEC-RAS 5 model to obtain a description of the flood inundation for the area. The simulated flood depths compared with measured data show a somewhat similar trend and corresponding values. However, a more detailed calibration cannot be performed because of the limitation of measurable data. Indeed, in the study area, there is no any water level recorder and or flood gauge. Nevertheless, the results of this study have demonstrated the enormous potential use of UAV in the future to acquire high-resolution elevation data for generating a detailed

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and accurate flood inundation map. The authors believe that the utilization of UAVs will be more extensive for flood control and management strategies, especially in Indonesia due to its flexibility, reliability and affordable cost.

4.2 Future works

To obtain a more detailed description about the accuracy of the flood inundation map, in the next study, it is necessary to compare the results of the flood simulation generated by UAV-DEM and UAV-LiDAR with different DEM resolutions or grid sizes. Also, it is essential to test the model of flood inundation in the area with a steeper topography to obtain a complete description of how the effectiveness of DEM-UAV on the simulation results of flood inundation. This study only deals with flood depths, while other parameters such as flow velocities, propagation time, and time of flooding are not discussed. Therefore, further research that addresses these parameters is also necessary to do.

5. CONCLUSIONS

Based on the results obtained above, it can be concluded that high-resolution DEM map can be efficiently generated using UAV survey. The flood simulation using UAV-based DEM can provide a clear picture of potential flooding in the study area. It is demonstrated by the comparison between the simulation results and the corresponding field observations. Therefore, its application in flood management and control strategy needs to be widely developed. Based on the simulation result, the flood depth at the study area varies between 0 - 1.5 m for Bukit Sejahtera residence, and 0 - 4.25 m for Tanjung Rawa residence. The areas closed to the Lambidaro River have higher floods depth and risks than other areas further from the river. Therefore, in term of flood control in the study area, for the structural approaches, it is recommended to build a dike or flood wall along the river to avoid overflowing water especially during high tides and heavy rainfall. For further research, it is advisable to compare the flood simulation generated by DEM-UAV and DEM-LiDAR. Also, the calibration using measured data with a sufficient number of flood gauges needs to be done for the study area to obtain a more accurate description of the potential flood.

ACKNOWLEDGMENTS

The authors would like to thank Universitas Sriwijaya for funding this research. The authors also extend their gratitude to the undergraduate students of Civil Engineering Department of Universitas Sriwijaya, which are supervised by the authors who have assisted in surveying and collecting data.

REFERENCES

Ajayi, O. G., Salubi, A. A., Angbas, A. F., & Odigure, M. G. (2017). Generation of accurate digital elevation models from UAV acquired low percentage overlapping images. *International Journal of Remote Sensing*, *38*(8–10), 3113–3134. https://doi.org/10.1080/01431161.2017.1285085

Al Amin, M. B., Sarino, & Haki, H. (2017). Floodplain Simulation for Musi River Using Integrated 1D / 2D Hydrodynamic Model. In *MATEC Web of Conferences. SICEST 2016* (Vol. 5023, pp. 1–5). Bangka, Indonesia. Retrieved from https://www.matec-conferences.org/articles/matecconf/pdf/2017/15/matecconf_sicest2017_05023.pdf

Al Amin, M. B., Sarino, & Sari, N. K. (2015). Visualisasi Potensi Genangan Banjir di Sungai Lambidaro Melalui Penelusuran Aliran Menggunakan HEC-RAS (Studi Pendahuluan Pengendalian Banjir Berwawasan Lingkungan). In *Prosiding Seminar Nasional Teknik Sipil I (SeNaTS I)* (Vol. 1, pp. 123–132). Bali, Indonesia.

Brandt, S. A., & Lim, N. J. (2016). Visualising DEM-related flood-map uncertainties using a disparity-distance equation algorithm. In *Proceedings of the International Association of Hydrological Sciences* (Vol. 373, pp. 153–159). https://doi.org/10.5194/piahs-373-153-2016

Coveney, S., & Roberts, K. (2017). Lightweight UAV digital elevation models and orthoimagery for environmental applications : data accuracy evaluation and potential for river flood risk modelling. *International Journal of Remote Sensing*, *0*(0), 1–22. https://doi.org/10.1080/01431161.2017.1292074

De Silva, T., Kahandagamage, R., Sanjeewa, I., Kulasinghe, C., & Ariyarathne, R. (2016). Generating more accurate digital elevation models incorporating off the shelf GIS software by using drone imagery. In *37th Asian Conference on Remote Sensing, ACRS*. Colombo.

Entwistle, N., & Heritage, G. (2017). An evaluation DEM accuracy acquired using a small Unmanned Aerial Vehicle across a riverine environment. *International Journal of New Technology and Research (IJNTR)*, *3*(7), 43–48.

Farid, M., Marlina, A., & Kusuma, M. S. B. (2017). Flood hazard mapping of Palembang City by using 2D model. In *AIP Conference Proceedings* (Vol. 100009, pp. 1–11). American Institute of Physics Articles. https://doi.org/10.1063/1.5011619

Haile, A., & Rientjes, T. (2005). Effects of LiDAR DEM resolution in flood modelling: a model sensitivity study for the city of Tegucigalpa, Honduras. In *Isprs Wg Iii/3, Iii/4* (pp. 168–173). Retrieved from http://www.isprs.org/proceedings/XXXVI/3-W19/papers/168.pdf

Hashim, S., Mohd, W., Wan, N., & Adnan, N. A. (2016). Evaluation of Vertical Accuracy of Airborne IFSAR and Open-Source Digital Elevation Models (DEMs) for Flood Inundation Mapping. In *Regional Conference on Science, Technology and Social Sciences (RCSTSS 2014)*. https://doi.org/10.1007/978-981-10-1458-1

Hsu, Y. C., Prinsen, G., Bouaziz, L., Lin, Y. J., & Dahm, R. (2016). An Investigation of DEM Resolution Influence on Flood Inundation Simulation. *Procedia Engineering*, *154*, 826–834. https://doi.org/10.1016/j.proeng.2016.07.435

Hudec, P. (2011). Analysis of Accuracy of Digital Elevation Models Created From Captured Data By Digital. *Slovak Journal of Civil Engineering*, *XIX*(4), 28–36.

Jeong, H. H., Park, J. W., Kim, J. S., & Choi, C. U. (2016). Assessing the accuracy of ortho-image using photogrammetric unmanned aerial system. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* (Vol. XLI-B1, pp. 867–872). Prague, Czech Republic. https://doi.org/10.5194/isprsarchives-XLI-B1-867-2016

Küng, O., Strecha, C., Beyeler, A., Zufferey, J.-C., Floreano, D., Fua, P., & Gervaix, F. (2011). The Accuracy of Automatic Photogrammetric Techniques on Ultra-Light UAV Imagery. In *ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (Vol. XXXVIII-1/, pp. 125–130). https://doi.org/10.5194/isprsarchives-XXXVIII-1-C22-125-2011

Madawalagama, S. L., Munasinghe, N., Dampegama, S., & Samarakoon, L. (2016). Low Cost Aerial Mapping With Consumer-Grade Drones. In *37th Asian Conference on Remote Sensing*. Colombo.

Marks, K., & Bates, P. (2000). Integration of high-resolution topographic data with floodplain flow models. *Hydrological Processes*, *14*(11–12), 2109–2122. https://doi.org/10.1002/1099-1085(20000815/30)14:11/12<2109::AID-HYP58>3.0.CO;2-1

Patel, D. P., Ramirez, J. A., Srivastava, P. K., Bray, M., & Han, D. (2017). Assessment of flood inundation mapping of Surat city by coupled 1D/2D hydrodynamic modeling: a case application of the new HEC-RAS 5. *Natural Hazards*, *89*(1), 93–130. https://doi.org/10.1007/s11069-017-2956-6

Pichon, L., Ducanchez, A., Fonta, H., & Tisseyre, B. (2016). Quality of Digital Elevation Models obtained from Unmanned Aerial Vehicles for Precision Viticulture. *OENO One*, *50*(3), 101–111. https://doi.org/10.20870/oeno-one.2016.50.4.1177

Putra, E. S., Suryadi, F. X., Tarigan, K., Bastari, A., & Sylvia, M. (2011). Strategy of Drainage and Flood Control in Palembang City.

Quiroga, V. M., Kure, S., Udo, K., & Mano, A. (2016). Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: Application of the new HEC-RAS version 5. *RIBAGUA - Revista Iberoamericana Del Agu*, *3*(1), 25–33. https://doi.org/10.1016/j.riba.2015.12.001

Ruzgiene, B., Berteska, T., Gecyte, S., & Jakubauskiene, E. (2014). Photogrammetric Processing of UAV Imagery : Checking DTM. In *The 9th International Conference "Environmental Engineering"* (pp. 1–6). Vilnius, Lithuania. Retrieved from http://enviro.vgtu.lt

Santise, M., Fornari, M., Forlani, G., & Roncella, R. (2014). Evaluation of dem generation accuracy from UAS imagery. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives* (Vol. 40, pp. 529–536). Riva del Garda, Italy. https://doi.org/10.5194/isprsarchives-XL-5-529-2014

Sze, L. T., Cheaw, W. G., Ahmad, Z. A., Ling, C. A., Chet, K. V., Lateh, H., & Bayuaji, L. (2015). High resolution DEM generation using small drone for interferometry SAR. In *International Conference on Space Science and Communication, IconSpace* (pp. 366–369). Langkawi, Malaysia. https://doi.org/10.1109/IconSpace.2015.7283801

Wedajo, G. K. (2017). LiDAR DEM Data for Flood Mapping and Assessment ; Opportunities and Challenges : A Review. *Journal of Remote Sensing & GIS*, *6*(4), 2015–2018. https://doi.org/10.4172/2469-4134.100021