iES Journal

Innovative Engineering and Sustainability
Journal Homepage: https://iesj.ft.uns.ac.id
Article ID: 1(2):61-72

Examining the Flooding Potentials in Surakarta City, Indonesia

R Hadiani[1], S As'ad[2], A S Permana[3]
[1]Email: rintis.hadiani@gmail.com, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, Indonesia
[2]Email: sholihinasad@gmail.com, Faculty of Engineering, Universitas Sebelas, Surakarta, Indonesia
[3]Email: ariva.pe@kmitl.ac.th, School of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand

A B S T R A C T

Floods may bring in both negative and positive impacts to society, the positive impacts, for example, in Nile river delta. In the Surakarta City, the floods bring largely negative effects, sometime loss of life. Urban floods of Surakarta City are so far caused by two generic proceedings of exceedance of river capacity and lacks of urban drainage. It has been exacerbated by the incompatibility of communities' activities with respect to flood. Inadequate flood prevention facilities have also been the trigger to urban flood in the city. The climate change may be one of the causes as well. However, we have no data to measure the contribution of this global phenomenon on the local urban flood. This study investigates the depth and duration of the inundated urban lands due to floods of the prominent tributaries of Bengawan Solo River in Surakarta City, since these variables determine the extent of the impacts and losses. These two variables were determined from the running of HEC-RAS river analysis program, with the inputs of hydrographs for particular flood return period along with geographical data of the city. The results show that inundation depth could reach a height of up to 4.0 m, varying with the duration.

Keywords: HEC-RAS, flood inundation depth, duration of inundation, Surakarta City

ARTICLE HIGHLIGHTS

Received: September 2022

Received in Revised Form: December 2022

Published Online: December 2022.

Keywords: HEC-RAS, flood inundation depth, duration of inundation, Surakarta City.

DOI: pro memory.

1. Introduction

Floods are, in simple terms, caused by the exceedance of river capacity by existing discharge, or by lack of drainage capacity to swiftly release the excessive overland flow. This event can be exacerbated by global phenomena of climate change (Bronstert, 2003; Poff, 2002), through more frequent and intense rainfall, rising sea levels, and therefore causing more frequent floods. From the geographic viewpoint, a city leveling off with adjacent rivers, effects would be more, with more coverage in terms of socio-economic and environmental aspects, with tangible and intangible losses. Even though floods can theoretically be fully controlled by current technology, this phenomenon is still relevant to be discussed as many developing cities are struggling to cope with the impacts of floods (Kourgialas & Karatzas, 2011; Birkholz et al., 2014).

Despite its natural characteristics that we will not be able to exterminate the flood events (Seifert et al., 2013; Lane, 2017), flood management and mitigation, which is aimed at reducing the impacts of the flood, may include a broad diversity of programs and works, from structural measures to non-structural measures (Sato, 2006;

Heidari, 2009; Faisal et al., 1999). This principle of flood prevention works may equally be applied in both rural and urban areas (Pudar et al., 2020; Cuny, 1991). The City of Surakarta has also applied this principle in its efforts to cope with floods.

Surakarta, Indonesia is a city with an area of 44.04 sq. km and a population of 517,887 as of 2021, or with a population density of 11,800 population per sq. km (Figure 1). The river of Bengawan Solo crosses the city, and therefore the city has been highly affected by and suffering from the behavior of the river for a long time. This densely populated city is passed through by six principal tributaries of Bengawan Solo, namely, Pepe Hulu River, Gadjah Putih River, Pepe Hilir River, Jenes River, Premulung River, and Wingko River. These tributaries carry two diametrically opposite functions to the city. During the low-flow period, the tributaries discharged partially urban wastewater, this is the constructive function of the tributaries. On the other hand, during the flood seasons, where the rainfall intensity in the watershed and the discharges in the tributaries are synchronously high. This has been studied for quite a long time. The recent studies are, for example, by Sholi et al., (2020), Pratama and Hadiani (2019), Ishadi et al. (2018).

Figure 1 Surakarta City, Indonesia

Studies by Utomo (2018), Aji et al. (2019), and Buana et al. (2018) have shown that the floods in Surakarta City as a result of the overflow of the tributaries toward the city are hydrologically caused by two-consecutive-day rainfall of 120 mm/day in total. However, 1-day rainfall of 90 mm/day may cause almost the same impacts as the earlier one. Moreover, the rainfall intensity of 50 mm/hour for 90 minutes is sufficient to generate one-third of the flood-vulnerable area in Surakarta City flooded. Through this experience along with the studies of these rivers, the city authority could take decisions on the flood occurrences in the city to avoid or minimize the losses through a flood warning system. The city authority has also prepared a flood risk mapping for a flood warning system in line with the flood prevention works, as outlined by Sampson et. Al (2015), and Recanatesi et al. (2017).

The study attempts to examine the possible flood potentials in Surakarta City due to the Bengawan Solo River and its tributaries, and develop the estimated risks and losses to the city, for a particular rainfall intensity in the river basin, or discharges in the rivers. By this examination, the flood prevention authority would be able to have more options and visions to cope with flood losses and promote the water resources development for the people's well-being in the regions. The study was carried out by collecting secondary data on rainfall and river discharges, running the HEC-RAS model, delineating the flood-vulnerable areas, and simulating the flood depth with corresponding losses.

2. The City Flood Standards

Surakarta City is geographically within the watershed of Bengawan Solo. The Bengawan Solo itself has a watershed of about 15,600 sq. km and a length of about 600 km. The flood control and river management authority of this river basin is Bengawan Solo Flood Control and Water Management Authority (BBWS-BS), under the Ministry of Public Works and Human Settlements, a central government body. However, Surakarta City is not the lone local administration, the administrative boundary is within the Bengawan Solo river basin. There is nine other same-level (in total 10 including Surakarta City) local administration in two provinces of Central Java and East Java, namely Boyolali, Karanganyar, Sragen, Ngawi, Madiun, Bojonegoro, Gresik, Lamongan, and Tuban. The budget-wise, the BBWS-BS annual budget for flood prevention works comes from the central government i.e. Ministry of Public Works and Human Settlements. Despite the limited budget, the BBWS-BS must be able to distribute the budget proportionally to prevent floods in those 10 local administrations. Since the problems and needs are different among the ten local governments, the BBWS-BS should prioritize the flood prevention works in each area. However, the plan must be one integrated plan for the whole river basin. With this bureaucratic system, Surakarta City, which has concerned with preventing seasonal floods from creating losses in the city, must adjust its city development plan and streamline its plan with the whole plan of the river basin under BBWS-BS.

Based on the Water Resources Management Plan of Bengawan Solo River Basin of 2015, the estimated design discharge at Jurug Point, which is the point that the river and its tributaries contribute to the flood in Surakarta City, is shown in Table 1.

Table 1 Probability of Exceedance and Corresponding Discharges of Bengawan Solo

Remarks	The probability of exceedance in 1-year (percent)	Corresponding Discharge (m^3/s)
Q-2	50	709
Q-5	20	975
Q-10	10	1044
Q-25	4	1209
Q-50	2	1331
Q-100	1	1454

Current flood control works protect Surakarta City from the occurrence of floods with the probability of exceedance of 4 percent per year. This probability corresponds to the discharge of the Bengawan Solo River of 1209 m^3/s. With this protection, when the existing discharge is above 1209, Surakarta City will be flooded. The selection of the design discharge was based on the financial capacity of the BBWS-BS allocated to Surakarta City and the budget provision by the local government of Surakarta City for the protection of the city from a flood event. The flood protection work should preferably apply with the smallest probability of exceedance possible. However, it consequently carries a huge quantity of protection works with an enormous budget provision, which is not possible considering the existing financial capacity of the local government. In the Bengawan Solo Water Resources Management, it was stated that the flood protection standard for the City would be increased gradually in line with the increasing financial capacity of the government.

The stage-wise works of flood protection, considering the financial capacity of the government, have brought into the design that allows the works are done in a phased format, without a necessity to remove the previous work, which would lead to cost inefficiency. The phased format of the work is illustrated in Figure 2. This work would finally terminate at the Standard Project Flood, which usually corresponds to the probability of a flood of 1 percent per year.

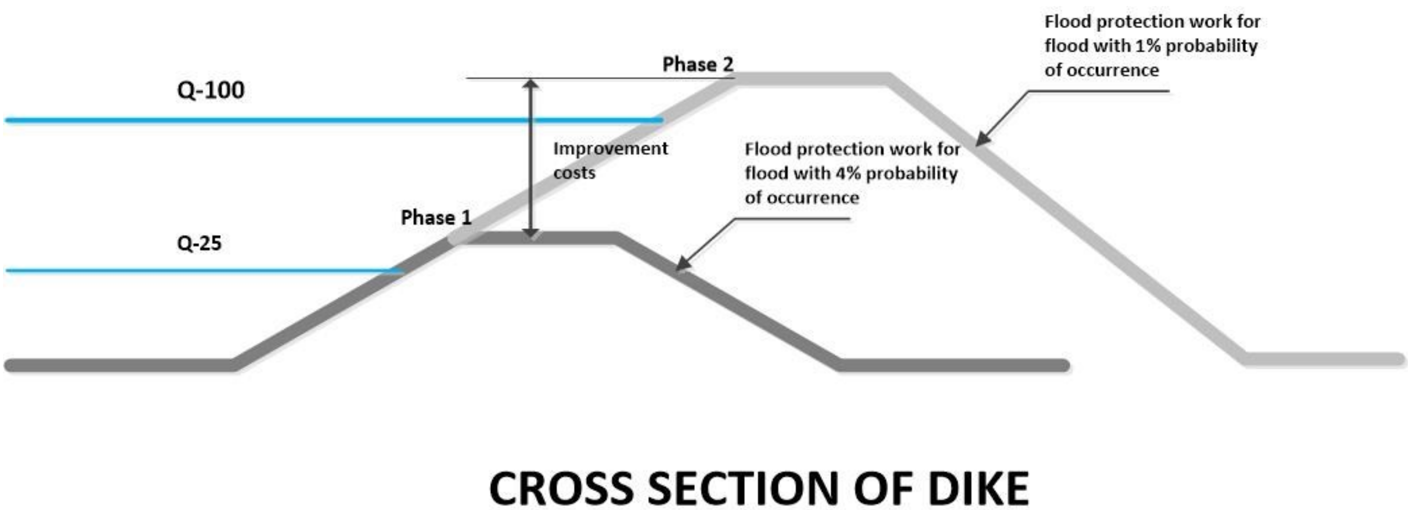

Figure 2 Phased Format of Flood Protection Works

3. The Analysis

The flood in Surakarta City due to the Bengawan Solo River and its tributaries occurred almost every two years. However, the largest flood in the City occurred in 1966, in which almost two-thirds of the city was inundated by a flood of 20 to 80 cm in depth for the duration of three hours to two days, depending on the region of the city. The recent considerably big flood was in 2016. However, the impacts were far below the 1966 flood, as the flood prevention works were functioning well to prevent the extent of the flooded area within the city.

The examination of flooding potentials in Surakarta City has been proven by reviewing the historical data of floods in Surakarta City, which shows that the city unarguably is flood-vulnerable. This is the ultimate proof of the city's vulnerability. Also, by assessing the facts that geographically, the city is subject to floods. The remaining inquiry is by employing scientific analysis of how to ensure flood impacts can be minimized and do not generate extensive effects on the city and citizens. Through this inquiry, we carried out the hydrologic and hydraulic analysis of the floods providing available relevant data for the analysis. We largely employ the US Army Hydraulic Engineering Center of River Analysis System (HEC-RAS), free but powerful software to analyze this phenomenon. The hydraulic analysis by using HEC-RAS was accompanied by the geographical data of Surakarta City obtained from the digital elevation map with an accuracy of 0.1 m.

The HEC-RAS is capable of performing one-dimensional and two-dimensional hydraulic calculations for a network of natural rivers or artificial channels. This study needs to determine the inundated area for a particular design hydrograph (as an input of unsteady flow to the system). The outputs of the system are required to understand the depth and velocity of flow on the river floodplain. A two-dimensional analysis of the part of the river floodplain was done. It was only part of the floodplain since it might require a long computer time to process the whole area of the floodplain i.e. around 1,500,000 sq. m^2.

The geometric input data into the HEC-RAS model was derived from the results of the terrestrial survey of the four Bengawan Solo tributaries i.e. Kalianyar, Kalipepe, Kalijenes, and Kalisewu Rivers. The data processed for the input into the HEC-RAS model are chronologically discussed below.

a Flow Hydrograph Inputs

The input into the HEC-RAS model was derived from the hourly rainfall in the upper basin of the Bengawan Solo River which covers the sub-basins in Surakarta City that generates flood in the city. The 3-hourly rainfall was selected for a reason that the urban flood in Surakarta City was largely generated by this rainfall pattern. At this point, further analysis of 3-hourly rainfall with the probability of exceedance of 4 and 10 percent respectively was analyzed to obtain the corresponding maximum flood discharge of the same probability of exceedance of 4 percent (locally termed as Q-25) and 10 percent (Q-10). The dimensionless hydrograph of the Natural Resources Conservation Service method, with the following set of equations, was used:

The peak discharge is determined by:

$$q_p = \frac{2.08A}{T_p} \quad [1]$$

$$T_p = \frac{t_r}{2} + t_p \quad [2]$$

$$t_p = 0.6T_c \quad [3]$$

Where: q_p peak discharge corresponding to a particular probability of exceedance in m^3/s
A catchment area in km^2
T_p Time to peak in hours
t_R time from the beginning of the rainfall to the center of gravity of the rainfall in hours
t_p time from the gravity of rainfall to the peak discharge in hours
T_c time of concentration, which is the time when all parts of the watershed contributed to runoff

The time of concentration was calculated by the following equation

$$T_c = 0.0078\left[\frac{L^{0.77}}{S^{0.385}}\right] \quad [4]$$

Where L length of the river
S bed slope of the river

The transfer process of the 24-hour depth of rainfall into any hourly rainfall depth was calculated by:

$$R_t = \left(\frac{R_{24}}{24}\right)\left(\frac{24}{t}\right)^{2/3} \quad [5]$$

Where R_{24} 24-hour rainfall depth
R_t Rainfall depth of time t

b Hourly Rainfall Distribution

From the analysis, the 3-hourly rainfall depth which corresponds to the probability of exceedance of 10 percent (R_{10}), 5 percent (R_{20}), 4 percent (R_{25}), and 2 percent (R_{50}) is shown in Table 2.

Table 2 Design Rainfall for Urban Flood in Surakarta City

Hourly Distribution	R_{10} (mm)	R_{20} (mm)	R_{25} (mm)	R_{50} (mm)
Hour-1	11	12	13	14
Hour-2	61	68	73	78
Hour-3	16	17	19	20

c Flood Discharge

Based on the design rainfall shown in Table 2, and the unit hydrograph developed earlier, the flood hydrograph input into the HEC-RAS model is established as shown in Tables 3 to 6, below.

Table 3 Flood Discharge in m^3/s with 10 Percent Probability of Exceedance (Q-10)

Hour	Kalianyar	Kalipepe	Kalijenes	Kalisewu
1	0	0	0	0
2	0.2	0.2	0.1	0.1
3	10.7	12.4	5.0	4.8
4	15.3	17.8	7.0	6.5
5	15.4	18	6.8	6.1
6	14.9	17.3	6.3	5.5
7	14.1	16.4	5.7	4.8
8	13.1	15.3	5.2	4.2
9	12.2	14.2	4.6	3.6
10	11.2	13.1	4.1	3.1
11	10.3	12	3.7	2.6
12	9.4	11	3.2	2.2
13	8.6	10	2.8	1.9
14	7.8	9.1	2.5	1.6
15	7.1	8.3	2.2	1.3
16	6.4	7.5	1.9	1.1
17	5.8	6.8	1.7	1.0
18	5.3	6.1	1.5	0.8
19	4.8	5.5	1.3	0.7
20	4.3	5.0	1.1	0.6
21	3.9	4.5	1.0	0.5
22	3.5	4.1	0.8	0.4
23	3.1	3.7	0.7	0.3
24	2.8	3.3	0.6	0.3
25	2.5	3	0.6	0.2

Table 4 Flood Discharge in m^3/s with 5 Percent Probability of Exceedance (Q-20)

Hour	Kalianyar	Kalipepe	Kalijenes	Kalisewu
1	0	0	0	0
2	0.2	0.3	0.1	0.1
3	12.8	14.9	6	5.8
4	18.2	21.2	8.3	7.7
5	18.3	21.3	8.0	7.2
6	17.7	20.6	7.5	6.5
7	16.7	19.5	6.8	5.7
8	15.6	18.2	6.2	4.9
9	14.5	16.8	5.5	4.3
10	13.3	15.5	4.9	3.6
11	12.2	14.2	4.3	3.1
12	11.2	13.0	3.8	2.6
13	10.2	11.9	3.4	2.2
14	9.3	10.8	3.0	1.9
15	8.4	9.8	2.6	1.6
16	7.6	8.9	2.3	1.3
17	6.9	8.0	2.0	1.1
18	6.2	7.3	1.7	1.0
19	5.6	6.6	1.5	0.8
20	5.1	5.9	1.3	0.7
21	4.6	5.4	1.1	0.6
22	4.1	4.8	1.0	0.5
23	3.7	4.3	0.9	0.4
24	3.4	3.9	0.8	0.3
25	3.0	3.5	0.7	0.3

Table 5 Flood Discharge in m^3/s with 4 Percent Probability of Exceedance (Q-25)

Hour	Kalianyar	Kalipepe	Kalijenes	Kalisewu
1	0	0	0	0
2	0.3	0.4	0.1	0.1
3	14.3	16.7	6.8	6.5
4	20.3	23.6	9.2	8.6
5	20.4	23.8	8.9	8.1
6	19.7	22.9	8.3	7.2
7	18.6	21.7	7.6	6.4
8	17.4	20.3	6.9	5.5
9	16.1	18.8	6.1	4.7
10	14.8	17.3	5.5	4.1
11	13.6	15.9	4.8	3.5
12	12.5	14.5	4.3	2.9
13	11.4	13.2	3.8	2.5
14	10.3	12	3.3	2.1
15	9.4	10.9	2.9	1.8
16	8.5	9.9	2.5	1.5
17	7.7	9	2.2	1.3
18	7	8.1	1.9	1.1
19	6.3	7.3	1.7	0.9
20	5.7	6.6	1.5	0.7

Hour	Kalianyar	Kalipepe	Kalijenes	Kalisewu
21	5.1	6	1.3	0.6
22	4.6	5.4	1.1	0.5
23	4.2	4.8	1	0.4
24	3.7	4.4	0.8	0.4
25	3.4	3.9	0.7	0.3

Table 6 Flood Discharge in m^3/s with 2 Percent Probability of Exceedance (Q-50)

Hour	Kalianyar	Kalipepe	Kalijenes	Kalisewu
1	0	0	0	0
2	0.4	0.4	0.2	0.2
3	15.8	18.5	7.5	7.2
4	22.3	26	10.2	9.5
5	22.5	26.2	9.8	8.9
6	21.7	25.2	9.2	8
7	20.5	23.9	8.4	7
8	19.1	22.3	7.5	6.1
9	17.7	20.7	6.7	5.2
10	16.3	19.0	6.0	4.5
11	15.0	17.5	5.3	3.8
12	13.7	16	4.7	3.2
13	12.5	14.6	4.1	2.7
14	11.4	13.2	3.6	2.3
15	10.3	12.0	3.2	2.0
16	9.4	10.9	2.8	1.7
17	8.5	9.9	2.4	1.4
18	7.7	8.9	2.1	1.2
19	6.9	8.1	1.9	1.0
20	6.2	7.3	1.6	0.8
21	5.6	6.6	1.4	0.7
22	5.1	5.9	1.2	0.6
23	4.6	5.3	1.1	0.5
24	4.1	4.8	0.9	0.4
25	3.7	4.3	0.8	0.3

4. Results and Discussions

With the inputs of digital terrain maps of 0.1 m accuracy of Surakarta City with a focus on the four sub-basins (z-coordinate), the geometric data from a terrestrial survey (x,y) coordinate, and flood hydrograph of four probabilities of exceedance (as shown in Tables 3 to 6), as the inputs into the HEC-RAS model, the flood inundation can be seen in Figure 3.

Figure 3 shows that the flood inundation generated by four tributaries of the Bengawan Solo River i.e. Kalianyar, Kalipepe, Kalijenes, and Kalisewu with the deepest was more than 4.0 meters. The depth ranges from 0.12 to 4.04 meters with a varying velocity of floodwater with the approximate inundation area for the probability of exceedance of 4 percent was about 400 hectares. This inundation is only generated by four tributaries. If the simulation involves the Bengawan Solo (the main river) for the same probability of exceedance, the inundation area would approximately increase 5 to 6 times. This shows the potential loss of 4 times floods in 100 years period. We estimated that the daily per hectare tangible and intangible losses due to the flood in Surakarta for the flood depth of 0.1 to a maximum of 0.8 meters is about IDR 0.8 billion (USD 50,000). Certainly, the magnitude and type of losses depend on the depth, duration, extent of the flood, and velocity of floodwater.

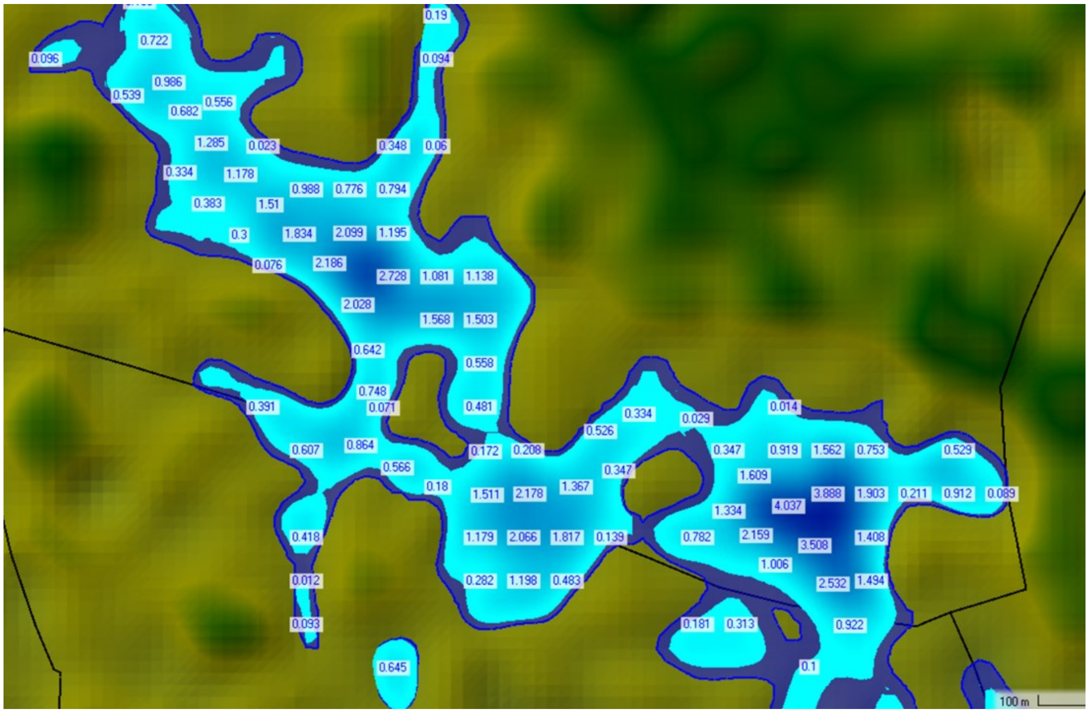

Figure 3 Inundation in Surakarta City Generated by Four Tributaries of Bengawan Solo

The superimpose of flood inundation on the City of Surakarta map is shown in Figure 4.

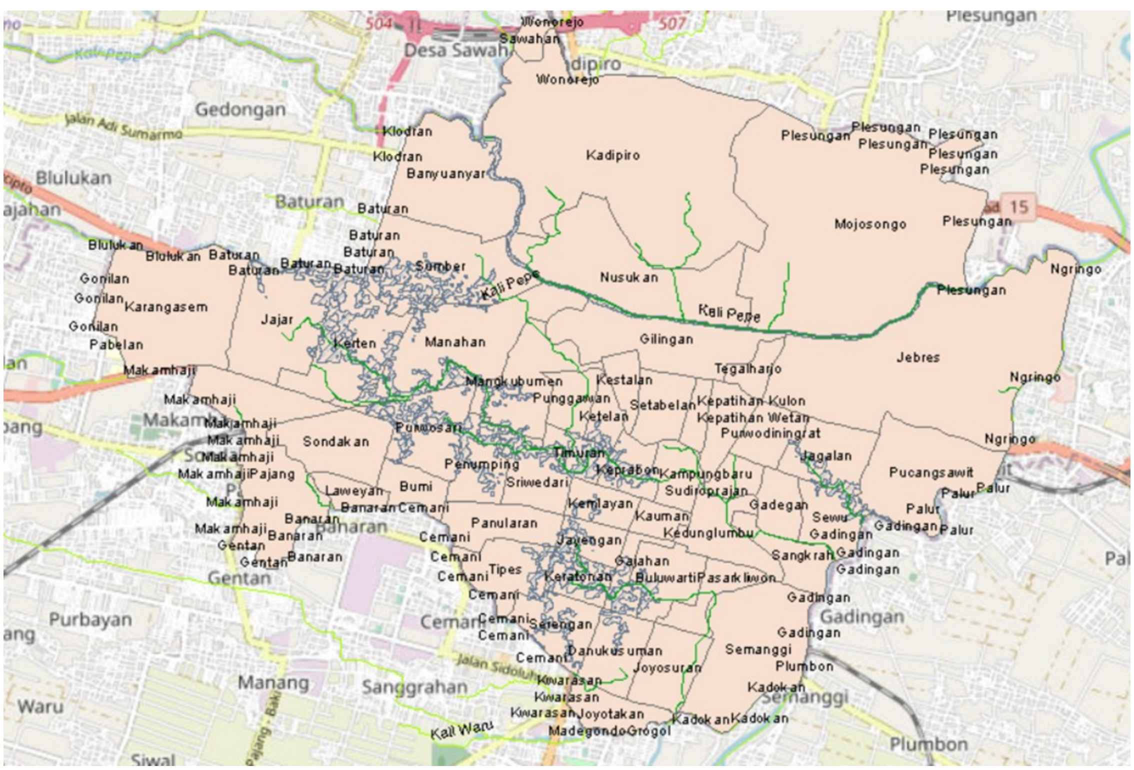

Figure 4 Urban Flood in Surakarta City due to Four Tributaries Only

The analysis shows that the depth of flood, and inundated areas in the city due to various levels of flood's probability of exceedance, as shown in Table 7

Table 7 Inundated Areas and Maximum Flood Depth for Various Probability of Exceedance

Variables	10% prob of exceedance (Q_{10})	5% prob of exceedance (Q_{20})	4% prob of exceedance (Q_{25})	2% prob of exceedance (Q_{50})	2-cons day of the flood
Inundated Area (ha)	204.0	233.3	257.8	279.3	404.8
Maximum Depth (m)	2.64	2.65	2.66	2.67	2.71

The tangible and intangible flood losses assessment can be done by referring to Permana, A. S. (2022) on the transfer functions to estimate the flood losses. The inundation and flood data to estimate the food losses must include the information shown in Figure 5.

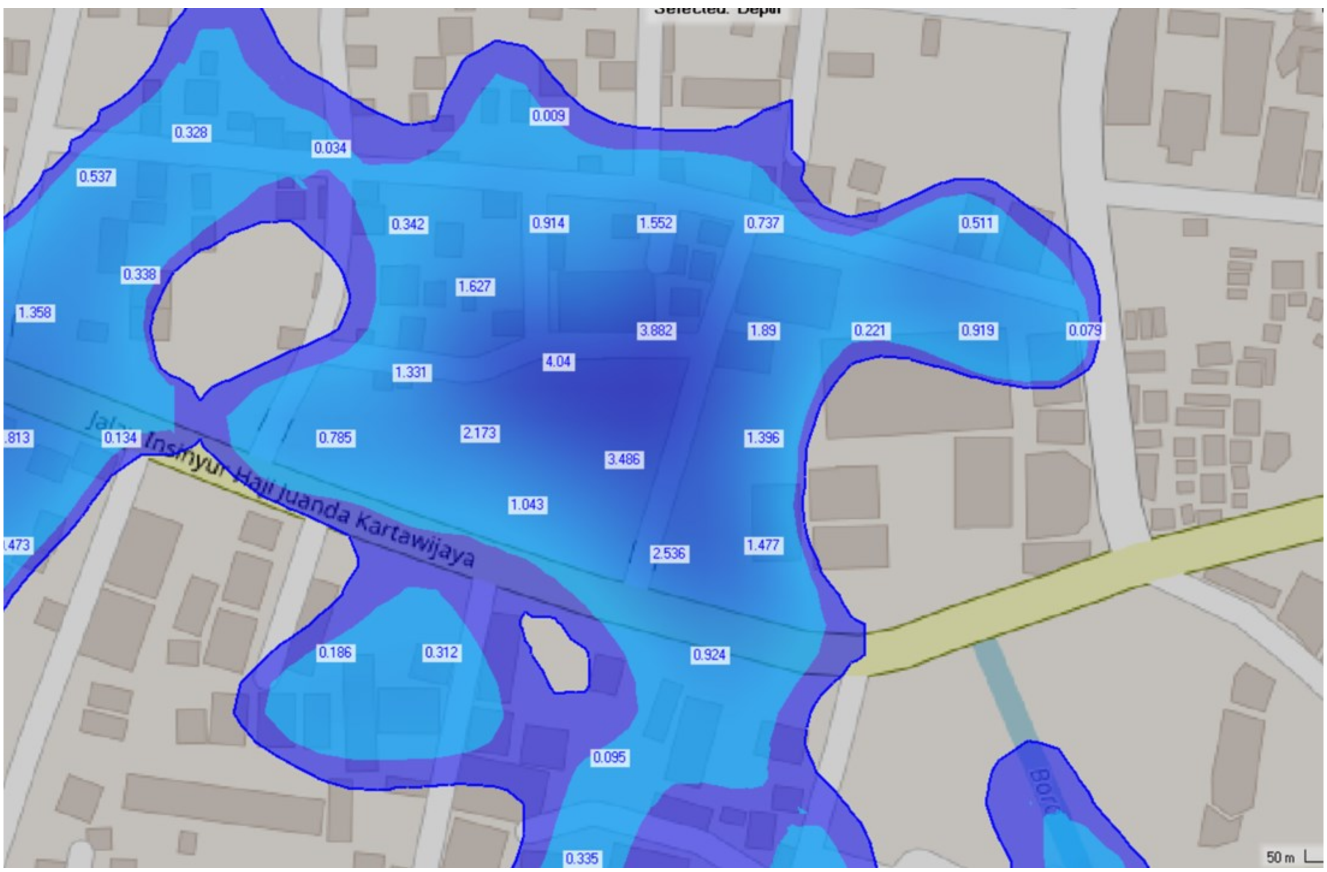

Figure 5 Inundation Depth and Urban Land Use

By understanding the flood and inundation data i.e. area, depth, duration, and floodwater velocity, the flood losses can be estimated. The Inundation map could also be used to solve urban flooding problems through structural and non-structural means, for instance, what types of flood control structures are required, how big the capacity, where is the location of the structures, and what accompanying non-structural measures required. The overall economic analysis of the flood control project could also be done with the same information at hand.

5. Way forward

Our analysis could be able to provide inputs to the flood authorities for flood control and prevention efforts to the flood authorities, as our outputs provide information on flood depth, duration areas, and coverage. If these variables are combined with detailed urban land use, an accurate estimate of flood losses could be easily done, and this would help the authority to make a decision. The authority referred to our study to construct the dike in some parts of the city.

To refine the results of the analysis, digital terrain data must be made available in higher resolution, and therefore the results of the analysis could be more accurate. In line with this improvement, the update on urban land use could also be done to acquire a more accurate estimation of flood losses. With more accurate information, the losses could also be estimated in a more precise way, the economic analysis could be carried out with higher accuracy, and eventually, the decision taken by the authorities could be more precise.

Acknowledgments

The support of Loughborough University, UK the Faculty of Engineering of Universitas Sebelas Maret, Indonesia, and the School of Engineering, King Mongkut's Institute of Technology Ladkrabang for this work is highly acknowledged.

References

Aji, D.A.S., Hadiani, R., Suryandari, E.S. (2019). *Analisis Banjir Dengan Standard Step Method Dan Pemetaan Banjir Di Kelurahan Joyotakan, Surakarta* (The flood analysis by using standard step method and flood mapping at Joyotakan, Surakarta). Matriks Teknik Sipil, Faculty of Engineering, UNS.

Birkholz, S., Muro, M., Jeffrey, P., & Smith, H. M. (2014). Rethinking the relationship between flood risk perception and flood management. *Science of the Total Environment*, 478, 12-20.

Bronstert, A. (2003). Floods and climate change: interactions and impacts. *Risk Analysis: An International Journal*, *23*(3), 545-557.

Buana, M.Z.R., Hadiani, R.R.R., Suryandari, E.S. (2018). *Analisis Banjir dengan Metode Muskingum Cunge dan Sistem Informasi Geografis di Kelurahan Banyuanyar, Surakarta* (The flood analysis by using Muskingum-Cunge method, and GIS at Banyuanyar, Surakarta). Matriks Teknik Sipil. Faculty of Engineering, UNS.

Cuny, F. C. (1991). Living with floods: alternatives for riverine flood mitigation. *Land use policy*, *8*(4), 331-342.

Faisal, I. M., Kabir, M. R., & Nishat, A. (1999). Non-structural flood mitigation measures for Dhaka City. *Urban water*, *1*(2), 145-153.

Heidari, A. (2009). Structural master plan of flood mitigation measures. *Natural Hazards and Earth System Sciences*, *9*(1), 61-75.

Pratama, H.B., Hadiani, R.R, (2019). *Analisis Banjir Tahunan Kota Surakarta dengan menggunakan Watershed Modelling System.* (Analysis of annual flood of Surakarta City by using Watershed Modelling System). Faculty of Engineering, UNS.

Ishadi, K.N., Hadiani, R., Suryandari, E.S. (2018). *Penelusuran Banjir berdasarkan Analisis Metode Kinematik Berbasis Sistem Informasi Geografis di Kelurahan Sangkrah Surakarta* (Flood routing by using GIS-based kinematic method), Faculty of Engineering, UNS.

Kourgialas, N. N., & Karatzas, G. P. (2011). Flood management and a GIS modelling method to assess flood-hazard areas—a case study. *Hydrological Sciences Journal–Journal des Sciences Hydrologiques*, 56(2), 212-225.

Lane, S. N. (2017). Natural flood management. *Wiley Interdisciplinary Reviews: Water*, *4*(3), e1211.

Permana, A. S. (2022). Transfer Functions of Monetizing the Intangible Benefits of Flood Control Works: *Innovative Engineering and Sustainability Journal,* 1(1), 28–37. Retrieved from https://iesj.ft.uns.ac.id/index.php/iesj/article/view/5

Poff, N. L. (2002). Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions of the Royal Society of London. Series A: Mathematical, Physical and Engineering Sciences*, *360*(1796), 1497-1510.

Pudar, R., Plavšić, J., & Todorović, A. (2020). Evaluation of green and grey flood mitigation measures in rural watersheds. *Applied Sciences*, *10*(19), 6913.

Recanatesi, F., Petroselli, A., Ripa, M.N., Leone, A. (2017). Assessment of stormwater runoff management practices and BMPs under soil sealing: a study case in a peri-urban watershed of the metropolitan area of Rome (Italy). *Journal of environmental Management*, 201: 6-18

Sampson, C.C., Smith, A.M., Bates, P.D. (2015). *A high-resolution global flood hazard model*. Water Resources Research, American Geophysical Union.

Sato, T. (2006). Fundamental characteristics of flood risk in Japan's urban areas. *A better integrated management of disaster risks: Toward resilient society to emerging disaster risks in mega-cities, Tokyo: TERRAPUB and NIED*, 23-40.

Seifert, I., Botzen, W. W., Kreibich, H., & Aerts, J. C. (2013). Influence of flood risk characteristics on flood insurance demand: a comparison between Germany and the Netherlands. *Natural Hazards and Earth System Sciences*, *13*(7), 1691-1705.

Sholi, I.N., Hadiani, R., Suryandari, S. (2020). *Analisis Kapasitas Drainase sebagai Upaya Pengendalian Banjir di Kelurahan Sangkrah, Surakarta* (Analysis of urban drainage capacity as a flood control effort, at Sangkrah Surakarta). Faculty of Engineering, UNS.

Utomo, E.S. (2018). *Analisis Banjir Dan Pemetaan Kawasan Terdampak Banjir Di Kelurahan Laweyan, Kota Surakarta* (Flood Analysis and Mapping of Flood Affected Areas in Laweyan, Surakarta). Faculty of Engineering, UNS.