1-D HEC-RAS modelling and the vulnerability level assessment of Belik River sub-watershed

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Abstract. Restoration of sub-watershed needs a comprehensive point of views because the climate change factors could affect any environment aspects inside it. The paper investigates the Belik River sub-watershed in Yogyakarta, Indonesia. The research aims to analyze the characteristics of the river in the study area and to assess its vulnerability level. The observation employs HEC-RAS supporting tool to simulate 1-D frames of the river to visualize the characteristics of the river. Then, the vulnerability level is evaluated by field survey to conclude the restoration strategy in the sub-watershed. There are two findings in this research: first, the river has a high level of vulnerability to the water-related disaster and second, the sub-watershed is classified as high-risk level of the endangered environment. Hence, the proposed restoration strategy is compulsorily needed to mitigate and to rehabilitate the sub-watershed. To conclude, the Belik River sub-watershed could be categorized as a red zone of high-risk level towards environmental vulnerability to flooding, contaminants, aquatic habitat, and social prosperity.

1. Introduction
Climate change in the last decade has changed the rainfall patterns that have occurred in various regions [1]. This problem has the impact of shifting the incidence and quantity of flood disasters to an increase, especially in urban areas [2]. The possibility of rainfall analysis in developing an area uses data from decades ago, while the dynamics of rainfall are always changing to be more extreme now [3]. Therefore, it is necessary to analyze the vulnerability of an area to climate change, especially during the rainy season. The arrival of floods in that season usually causes physical losses [4] and mental disorders of individuals [5]. Therefore, there are many studies on flood analysis to assess the vulnerability of a watershed so that mitigation and restoration can be carried out.

On the other hand, the impact occurs not only on humans and their property, but also on the environment, habitat, and the species that live and form food webs there [6]. Food web imbalances can result in an imbalance of the life cycle in an ecosystem. In supporting the analysis of the vulnerability of a watershed, besides the rainfall factor, environmental factors, pollution and aquatic habitats need to be considered in a watershed.

This study is a follow-up study of hydrological and hydraulic analysis in the Belik sub-watershed [7]. The results of this study indicate that Belik sub-watershed has a very high level of vulnerability to flooding. This is evidenced by modelling simulations using HEC-RAS and field observations in the form of secondary data collection documentation of flood events and interviews with residents related to flooding that occurred in the Belik sub-watershed. Since this research only discusses the problem of regional vulnerability to flooding, this study aims to fill the gap in the analysis of watershed vulnerability.
that has been carried out previously by assessing the vulnerability of environmental factors, pollution, aquatic habitat, and ecology.

2. Methods
In this study, watershed vulnerability analysis was carried out using two main methods, namely 1-D modelling using HEC-RAS software [8] and field surveys for environmental assessment, aquatic habitat, and pollution. The 1-D HEC-RAS analysis in this study is secondary data from previous studies [7]. So, this research is further analysis. Rain analysis was performed as input for visualization of river hydraulic characteristics which had been translated into HEC-RAS software. After that, the modelling results were analyzed regarding the inundation that occurred as the basis for determining the vulnerability of the watershed to flooding.

Flood modelling in the Belik sub-watershed was carried out using the HEC-RAS software. After the flood analysis was carried out from the available rainfall data, bathymetry visualization in the HEC-RAS software was carried out. Making bathymetric coordinates of the river channel will describe the condition of the river being reviewed. After all river alignment coordinates are formed, the flood discharge data input is carried out. This one-dimensional hydraulic inundation visualization will help determine which areas are prone to flooding.

After that, analysis of watershed vulnerability based on the environment such as river corridors and land use, aquatic habitat, and pollution is carried out through field surveys. This observation is based on the main method that has been proposed by Zielinski [9], depicted in Figure 1.

The research location is in Belik Sub-Watershed, as depicted in Figure 2 (a). The sub-watershed is situated in the middle of Yogyakarta city. Geographically, it is a catchment which lies between 7º45'28” south latitude to 7º49'3” south latitude and 110º22'33” east longitude to 110º23'24” east longitude. Furthermore, administratively, the sub-watershed involves two regencies, part of Sleman city and part of Yogayakarta city. The sub-watershed also covers part of Depok district, Gondokusuman district, Umbulharjo district, and small part of Pakualaman, Danurejan, and Mergansan district with total area of 6.84 km².

Figure 1. Research method for sub-watershed vulnerability assessment

3. Results and discussion
The vulnerability of watersheds due to flood inundation has been carried out in previous studies [7]. The results of this study revealed that the Belik sub-watershed experienced a high level of severe flooding during the rainy season which could be observed in Figure 2. This is reinforced in the HEC-RAS modelling and photos of flood events. From the results of this study, the category of vulnerability of the Belik sub-watershed to flooding and its hydraulic structure is high.

Based on the results of this flood analysis, it is concluded that the Belik sub-watershed, especially in Belik River, has a high vulnerability to flooding. In previous studies, analyzes of watershed vulnerability to environmental factors such as contaminants, water quality, and aquatic habitat have not been observed. This research is what will fill the gap.

Watershed vulnerability analysis was carried out by survey methods at several points to reveal the status and level of pollution and the presence of water habitats in the study area. According to Zielinski’s
method [9] of watershed vulnerability analysis, Table 1 and Table 2 describe the results of the river corridor assessment survey results and land use in the Belik sub-watershed. Figure 3 depicts photos of the results of the survey conducted in the Belik sub-watershed.

![Figure 2. Inundation modelling of Belik River by employing HEC-RAS](image)

![Figure 3. Field observation of Belik sub-watershed stream corridor](image)
Table 1. River corridor assessment

| Assessment criteria                                                                 | Information                                                                 | Checklist |
|------------------------------------------------------------------------------------|----------------------------------------------------------------------------|-----------|
| Presence of rare aquatic species in rivers                                          | There are several species of fish and amphibians in Belik River              | ✓         |
| There are fish species that are sensitive to pollution                              | Not found                                                                  | X         |
| Rank of invertebrates in the study area (checklist only when conditions are good)  | Few invertebrate                                                           | X         |
| The presence of EPT (Ephemeroptera, Plecoptera, and Trichoptera) more than 65% in river corridors | Found under 65%                                                            | X         |
| There are no obstacles to the movement of fish in the river                         | Yes                                                                        | ✓         |
| Minimum intervention river changes from normalization                               | There is a change in the shape of the river due to normalization or development interventions | X         |
| Water quality during the dry season                                                 | Low quality                                                                | X         |
| Connection of rivers and land                                                       | Yes                                                                        | ✓         |
| River water flows downstream from source water                                      | No                                                                          | X         |
| Stable water flow                                                                   | Yes                                                                        | ✓         |

Table 2. Land use assessment

| Assessment criteria                                                                 | Information                                      | Checklist |
|------------------------------------------------------------------------------------|--------------------------------------------------|-----------|
| Found populations of rare plants or animals in the watershed                       | Not found                                        | X         |
| Presence of wetlands, floodplains and green infrastructure in excess of 10%        | Found but below 10%                              | X         |
| There is a conservation area plan of more than 10% of the study area              | Not found                                        | X         |
| Riparian corridors in the watershed have more than 50% forest area                | Not found                                        | X         |
| There is forest in the entire watershed (minimum 40%)                               | Not found                                        | X         |
| The existence of an organization or agency that is responsible for managing vulnerable watersheds | Yes                                              | ✓         |
| The tributaries flow continuously                                                 | Yes                                              | ✓         |
| The sub-watershed is connected to a watershed that can accommodate wild animal life | Not found                                        | X         |
| The implementation of Best Management Practices (BMP) in animal husbandry and agriculture | Not found                                        | X         |
| There is management of water quality and quantity in the sub-watershed before it is developed into a certain condition | Yes                                              | ✓         |

Based on the river corridor and land use assessment in Table 1 and Table 2, the Belik sub-watershed only received 40% and 30% for the respective assessments. These results show that the vulnerability of the Belik sub-watershed from the river corridor and land use indicators is very high.

The extent of impervious cover in the Belik sub-watershed is 74.31% consisting of settlements of 28.66%, housing by 14.07%, offices by 25.53%, and shops of 6.05%. This is the result of research conducted by other studies [10] using 2012 data. The research predicted that the impervious cover percentage has an increasing trend.
Based on Figure 4, the percentage of impervious cover in the Belik sub-watershed is more than 60% and the river quality is poor, so the Belik sub-watershed is included in the category of restorable non-supporting watershed. This means that restoration efforts exist and have the possibility to be carried out, but the condition of the watershed is not supportive. Thus, solving this problem requires a water sensitive urban design approach [11] as has been done in several cities in other countries with high population density [12].

In this study, a preliminary analysis of the water sensitive urban design (WSUD) implementation was carried out. Before WSUD modelling which will be continued in the next analysis, this article contains what green infrastructure or technology can be applied by the conditions of the Belik sub-watershed.

3.1. Rainwater harvesting
Rainwater harvesting are commonly used in Indonesia. However, this has not been seen as a potential by urban communities. The benefits that can be taken from this rainwater harvesting are as rainwater reserves during the dry season and can reduce flooding during the rainy season. Based on previous research [13], rainwater harvesting can reduce flooding or runoff by 58% - 100%. Figure 5 explains the plumbing structure for rainwater harvesting that could be implemented in the study area.
3.2. Porous pavement

The Klitren area, Gondokusuman, Yogyakarta has a village that has a high vulnerability to flooding. Apart from the density of residential areas, there is almost no green space for runoff when it rains. An alternative that can be done is to install a water-escaping pavement. Many studies have proven the advantages of this porous pavement. Experiments that have been conducted [15], depicted in Figure 6, state that the reduction ability can reach 42.5% - 52.5%.

Apart from the two alternatives above, several technologies can be used in WSUD simulations, for example green wall, swale, and others. This alternative is then simulated using a model from the Storm Water Management Model (SWMM) software [16]. The result of the SWMM analysis is the ability to reduce the runoff that occurs. Apart from the quantity, the water quality in the Belik sub-watershed can also be simulated using this software.

4. Conclusion

Belik sub-watershed has high vulnerability to flooding, pollution and aquatic or ecological habitats. The existence of climate change will create a high level of uncertainty regarding the vulnerability of
watersheds if mitigation is not carried out. Mitigation in urban areas needs to be done using technology that can be simulated through SWMM software. Through this software, it can be analyzed how the quantity and quality of water based on several proposed scenarios.

References
[1] I Douglas 2009 Climate change, flooding and food security in south Asia Food Secur. 1 127–36
M M Q Mirza 2011 Climate change, flooding in South Asia and implications Reg. Environ. Chang. 11 SUPPL. 1 95–107
A T Silva and M M Portela 2018 Using climate-flood links and CMIP5 projections to assess flood design levels under climate change scenarios: a case study in Southern Brazil Water Resour. Manag. 32 4879–93
Y Zhou 2020 Exploring multidecadal changes in climate and reservoir storage for assessing nonstationarity in flood peaks and risks worldwide by an integrated frequency analysis approach Water Res. 185 116265
[2] P P Santos, A O Tavares, P Freire and A Rilo 2018 Estuarine flooding in urban areas: enhancing vulnerability assessment Nat. Hazards 93 s1 77–95
D Thorsteinssson, A Semadeni-Davies and R Larsson 2007 Planning for river induced floods in urban areas: Experiences and key issues for Sweden Adv. Nat. Technol. Hazards Res. 25 485–503
S Habel, C H Fletcher, T R Anderson and P R Thompson 2020 Sea-Level Rise Induced Multi-Mechanism Flooding and Contribution to Urban Infrastructure Failure Sci. Rep. 10 1–12
[3] J H Ahn, T W Kim, C Yoo and Y N Yoon 2003 On the variation of frequency-based rainfall amounts: A case study for evaluating recent extreme rainfalls in Korea Stoch. Environ. Res. Risk Assess. 17 217–27
S Joshi, K Kumar, V Joshi and B Pande 2014 Rainfall variability and indices of extreme rainfall-analysis and perception study for two stations over Central Himalaya, India Nat. Hazards 72 361–74
[4] O A Adeibimpe, D G Proverbs and V O Oladokun 2020 A fuzzy-analytic hierarchy process approach for measuring flood resilience at the individual property level Int. J. Build. Pathol. Adapt. (ahead-of-print)
[5] T W Collins, A M Jimenez and S E Grineski 2013 Hispanic health disparities after a flood disaster: Results of a population-based survey of individuals experiencing home site damage in El Paso (Texas, USA) J. Immigr. Minor. Heal. 15 415–26
A Crabtree 2013 Questioning Psychosocial Resilience After flooding and the consequences for disaster risk reduction Soc. Indic. Res. 113 711–728
E D Felix, T D Afifi, S M Horan, H Meskunas and A Garber 2020 Why family communication matters: the role of co-rumination and topic avoidance in understanding post-disaster mental health J. Abnorm. Child Psychol. 48 1511–24
N Nahar, Y Blomstedt, B Wu, I Kandarina, L Trisnantoro and J Kinsman 2014 Increasing the provision of mental health care for vulnerable, disaster-affected people in Bangladesh BMC Public Health 14 708
[6] D C Andersen, P B Shafroth, C M Pritekel and M W O’Neill 2011 Managed flood effects on beaver pond habitat in a desert riverine ecosystem, bill williams river, Arizona USA Wetlands 31 195–206
M Godlewskas, G Mazurkiewicz-Boroń, A Pociecha, E Wilk-Woźniak and M Jelonke 2003 Effects of flood on the functioning of the Dobczyce reservoir ecosystem Hydrobiologia 504 305–13
C. J. Talbot, E M Bennett, K Cassell, D M Hanes, E C Minor, H Pael, P A Raymond, R Vargas, P G Vidon, W Wollheim and M A Xenopoulos 2018 The impact of flooding on aquatic ecosystem services Biogeochemistry, 141 439–61
[7] R M S Prastica and D Wicaksono 2019 Integrated multimodal disaster mitigation management
for urban areas: A preliminary study for 2-d flood modelling IOP Conf. Ser. Mater. Sci. Eng. 650 012056

[8] S Ignatius, H. Soeryantono, E Anggraheni and D Sutijiningsih 2019 Analysis of flood inundation in North Sunter on the North Sunter Polder system performance IOP Conf. Ser. Mater. Sci. Eng. 669 012039

C C Abon, C P C David and G Q Tabios 2012 Community-based monitoring for flood early warning system: An example in central Bicol River basin, Philippines Disaster Prev. Manag. 21 85–96

[9] J Zielinski 2002 Watershed Vulnerability Analysis (Ellicott City, Maryland: Center for Watershed Protection)

[10] S Suprayogi, H Fatchurohman and M Widyastuti 2019 Analisis Kondisi Hidrologi terhadap Perkembangan Wilayah Perkotaan Studi Kasus DAS Belik River Yogyakarta J. Geogr. Media Inf. Pengemb. dan Profesi Kegeografi 16 153–61

[11] F Ahammed 2017 A review of water-sensitive urban design technologies and practices for sustainable stormwater management Sustain. Water Resour. Manag. 3 269–82

[12] M Kuller, P M Bach, D Ramirez-Lovering and A Deletic 2018 What drives the location choice for water sensitive infrastructure in Melbourne, Australia? Landsc. Urban Plan. 175 92–101

A Liu, Y Guan, P Egodawatta and A Goonetilleke 2016 Selecting rainfall events for effective Water Sensitive Urban Design: A case study in Gold Coast City, Australia Ecol. Eng. 92 67–72

J C Radcliffe, D Page, B Naumann and P Dillon 2017 Fifty years of water sensitive urban design, Salisbury, South Australia Front. Environ. Sci. Eng. 11 7

[13] X Zhang and M Hu 2014 Effectiveness of rainwater harvesting in runoff volume reduction in a planned industrial park, China Water Resour. Manag. 28 671–82

[14] H Traboulsi and M 2017 Traboulsi Rooftop level rainwater harvesting system Appl. Water Sci. 7 769–75

[15] W Liu, Q Feng, W Chen and R C Deo 2020 Stormwater runoff and pollution retention performances of permeable pavements and the effects of structural factors Environ. Sci. Pollut. Res. 27 30831–843

[16] G Zhao, Z Xu, B Pang, T Tu, L Xu and L Du 2019 An enhanced inundation method for urban flood hazard mapping at the large catchment scale J. Hydrol. 571 873–82

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