ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

Available online at
http://ojs.unik-kediri.ac.id/index.php/ukarst/index

U KaRsT

http://dx.doi.org/10.30737/ukarst.v5i1

Flood Vulnerability Assessment of Kali Welang Floodplain by Using Analytic Hierarchy Process Based Methods

A. D. Wicaksono [1], E. Hidayah [2*], R. U. A. Wiyono [3].

[1,2*,3] *Master Program in Civil Engineering, Departement of Civil Engineering, Faculty of Engineering, University of Jember.*

Email : [2*] *entin.teknik@unej.ac.id*

A R T I C L E I N F O

Article History :
Article entry : 03-12-2020
Article revised : 19-12-2020
Article received : 12-01-2021

Keywords :
AHP, Exposure, Floodplain, Susceptibility, Resilience, Vulnerability-index.

IEEE Style in citing this article :
[1] *B. Smit and J. Wandel, "Adaptation, adaptive capacity and vulnerability," Glob. Environ. Chang., vol. 16, no. 3, pp. 282–292, 2006, doi: 10.1016/j.gloenvcha.2006.03.008*

A B S T R A C T

Floods occur almost every year in a number of areas in the floodplain of Kali Welang. The floods have caused loss of materials and lives. Assessment of the vulnerability is essential for policy making in non-structural treatment of floods. The objective of this paper is to compute and elaborate the flood vulnerability index in local scale to assess conditions that affect the magnitude of flood hazards. This study identifies and evaluates the Flood Vulnerability Index (FVI) of an area by considering the factors of area's exposure to floods, flood susceptibility, and flood resilience. The Analytic Hierarchy Process (AHP) is used to formulate the weights of each component. The values of the components were collected from interviews with policy makers from relevant governmental agencies. The inputs for the AHP were collected from the respondents in a questionnaire survey. This study selected 18 relevant indicators. The FVI results show very high vulnerability in local scale in one village and high vulnerability in other six villages. The results of this study can be used to construct non-structural strategies in flood mitigation by enhancing community's resilience toward the flood. In addition, the results can be used for policy making process in spatial urban planning.

1. Introduction

Almost every year the floods occur in the lower part of Kali Welang (Welang River). The floods used to inundate housing areas, paddy fields, plantation areas, and main roads that connect provinces. The inundation of paddy fields, housing areas, and croplands has caused the local community great loss and suffering. The inundation of national roads will not only inflict local residents, but also the road users. In summary, the floods will cause great social and economic damages and will significantly change the environment.

96 - 109
ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

The floods on an area affect the vulnerability of the system in the area. The vulnerability is influenced by three main factors, namely exposure, susceptibility, and resilience. The vulnerability of an area in any scale reflects exposure and susceptibility of the danger conditions, while the resilience is the ability of the area to overcome the floods impacts [1], [2]. The exposure is a function of parameters including infrastructure, cultural heritage, agricultural fields, and the community affected by the floods. It is described as patterns and processes estimated from the intensity and the magnitude of the parameters [3]. When further explored, the three factors are part of economic, social, physical, and environmental components.

The climate change has been exacerbating situation because the climate change has potential to increase both the intensity and the magnitude of floods [4]. This increase will worsen the damage caused by the floods. Therefore, flood risk assessment on various spatial scales is highly necessary in minimizing the flood vulnerability. Smaller scale assessment can improve the decision making process in local scale so that local and regional vulnerability can be reduced [5]. The suitability of the assessment method largely depends on indicators suitable with the location. [6] categorizes flood vulnerability indicators by considering physical, social, economic, and environmental components. These components enable evaluation on the total impact of the flood vulnerability indices. By incorporating all components in the calculation, the resulted FVI is more reflective for the vulnerability status on the cities [7].

In determining the weight of the flood vulnerability indicators, some researchers have used the AHP method [8], [9] . This method is used by González in the weighted the indicator for social vulnerability capable of analyzing in detail for medium-sized cities [10]. Nasiri combines Delphi method with AHP to perform weighting indicators of social, physical, environmental and economic, wherein the method is able to describe the reality of the vulnerability of the flood in Kuala Lumpur city's districts [8]. Another application of AHP is used to map vulnerabilities in Coastal areas which allows to identify and prioritize more vulnerable areas [9].

The objective of this study is to present the use of FVI to categorize the areas in the floodplain of Kali Welang based on their vulnerability to the floods. The categories are very high vulnerability, high vulnerability, moderate vulnerability, low vulnerability, and very low vulnerability. To achieve the objective, the indicators of exposure, susceptibility, and resilience are used to categorize the vulnerability consequences of the floods. The indicators will be used to explore physical, social, economic, and environmental components in the study areas. The

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

results of the vulnerability assessment are highly needed for policy making in flood mitigation.

2. Literature Review

2.1 Study Area

Kali Welang is one of the rivers located in the northeast part of Jawa Timur (shown in Figure 1). This river is 36 kilometres long with the watershed area of 518 square kilometers. Almost every year, flooding occurs on the estuary of the river with the floodwater depth ranges between 50 and 100 centimetres [11]. Historical records of the floodings in Welang River show that during the flood with 10-year recurrence interval, the floodwater used to spill three-kilometers away into adjacent areas. The floodwater used to spill over the Pantura arterial road and seven villages, namely: Karangketug, Kraton, Pulokerto, Randusari, Sumare, Sukorejo dan Tambakrejo, as shown in Figure 1.

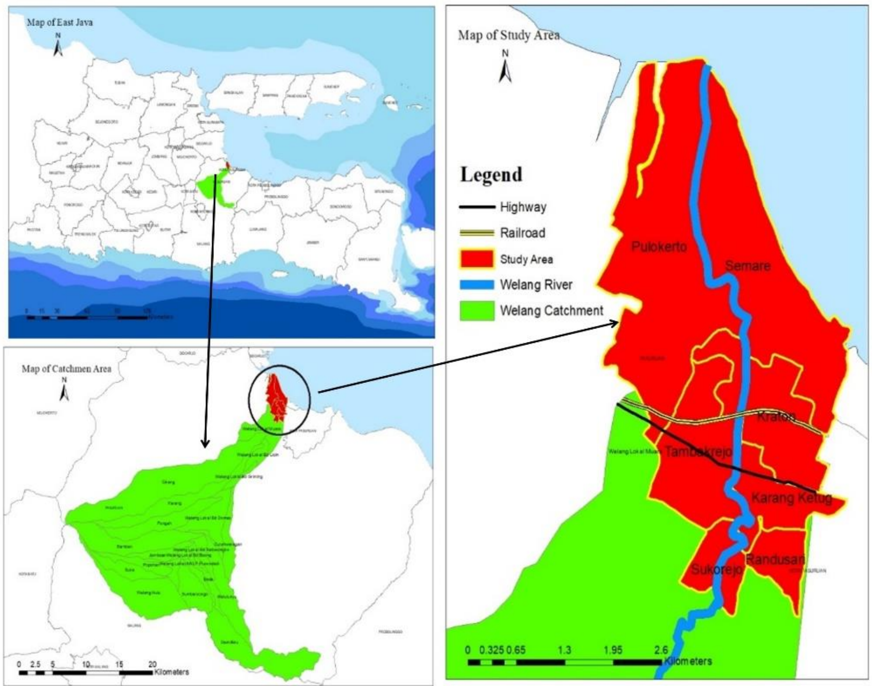


Figure 1. Study Area

2.2 The Concept of Vulnerability

Vulnerability is interaction among exposure, susceptibility, and resilience of each community in a risky condition [12]. Based on the definition, the concept of vulnerability in this paper is a function of three factors, namely exposure, susceptibility, and resilience [13]. Susceptibility is the damage caused by the floods in the area. Resilience is the ability of the area to naturally recover from the flood.

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

2.2.1 Exposure

The flood exposure factor is defined as "the predisposition of a system to be disrupted by a flooding event due to its location in the same area of influence" [13]. Factors that affect the flood vulnerability can be categorized into two groups. The first group include exposure to risky elements such as information on location, height, population density, and land use. The second group include details of general specification of the floods, namely information on the flood frequency in the floodplain or in the cities. The flood exposure is measured from the location of infrastructure, materials, cultural heritage, and the exposed communities.

2.2.2 Susceptibility

The mapping and the assessment of the flood susceptibility is an essential factor in flood mitigation because it identifies the most vulnerable area based on the physical characteristics that determine the tendency of floods[14]. Each area has distinct physical characteristics that influence the flood vulnerability. Several studies show that factors that affect the flood vulnerability in the local scale are the rain intensity, elevation, and type of soil [15], [16]. This study assumes that the elements of susceptibility are physical characteristics of an area that have negative impacts on the flood vulnerability.

2.2.3 Resilience

In the latest decade, resilience is broadly defined as the capacity to resist the impact of a disaster and to recover from the damage caused by the disaster. The concept of resilience was first introduced by Holling [17] to determine relationships in a system as a measure of the system's ability to adapt to any unexpected future events. Resilience is a factor of any system or community that indicates the ability to adapt to threats or to reduce the damage caused by dangerous events [18]. In this study, resilience means the ability of a system to reduce the impacts of the floods.

The relationship among exposure, susceptibility, and resilience is formulated in Equation in bellow.

$$FVI = \frac{Exposure\ x\ Subceptibility}{Recilience}$$

http://dx.doi.org/10.30737/ukarst.v3i2

Ukarst : Universitas Kadiri Riset Teknik Sipil.
Volume 5 Number 1, (2021).
ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

3. Methodology

The method used to develop the FVI as described in Figure 2 consists of five steps, namely: (1) selection of relevant indicators, (2) normalization, (3) weighting of the selected indicators, (4) aggregation to form FVI, and (5) map construction process.

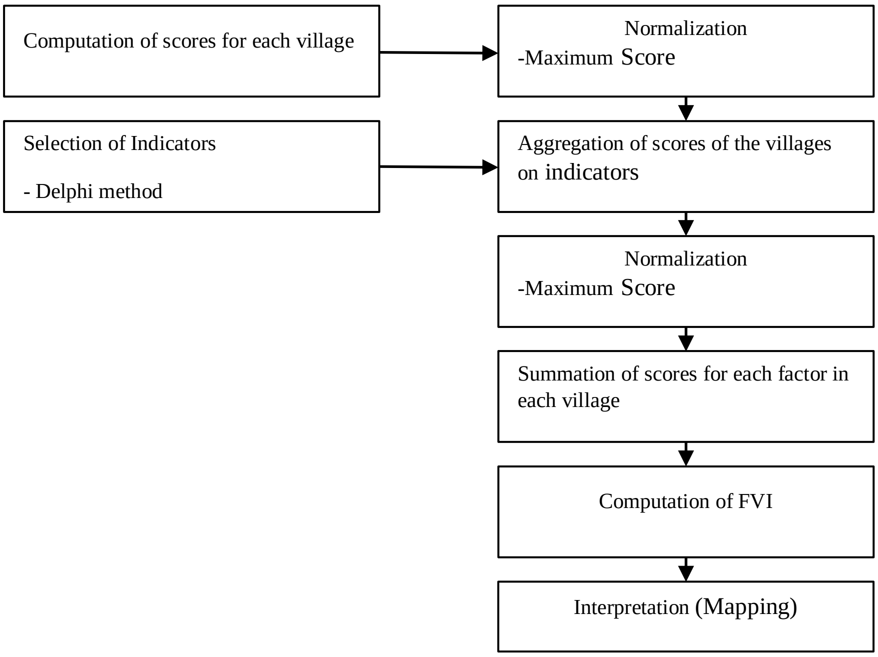


Figure 2. The Steps Used in The Development of an FVI

3.1. Selection of Indicators

The selection of relevant, actual indicators needs consideration of factors, such as suitability with the characteristics of the study area, clear conceptual framework or definitions, data accessibility, functionality, and easiness to remember [19]. The method to select indicators for FVI is quantitative method based on the views of experts [20]. The main quantitative method to select indicators in this study is a combination of Delphi technique with Analytic Hierarchy Process (AHP). The purpose of combining Delphi technique with AHP is to surmount the weakness of AHP in weighting, especially when more than 15 variables are used in AHP [21].

Analytic Hierarchy Process (AHP) was first introduced by Saaty on the 1997 [22]. This theory has been widely used in modeling uncertainties in decision making. AHP uses pairwise comparison matrices to obtain preference scales from a group of variables. Delphi method is used to obtain the views of experts by means of a series of questionnaires without having to gather the experts in an appointed place and time [21]. By using this method, the experts can value, modify, and present their opinions and suggestions on the issue being studied [23].

http://dx.doi.org/10.30737/ukarst.v3i2

100 - 109
ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

3.2 Normalization

After summarizing raw vulnerability indicator values for all villages, we normalized inter-villages indicator values to compute the FVI values. Normalization is conducted by considering the maximum value and the minimum one of each indicator in all villages to guarantee that the model input has range between 0 and 1[23]. Normalization should be conducted individually for each indicator [24]. The normalized input is computed based on general linear transformation as shown in Equation in bellow [25].

$$z_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

With Z_i is the normalized value, X_i is the *i*-th value, X_{max} is the maximum value, and X_{min} is the minimum value of i.

3.3 Weighting

The next step is assigning appropriate weights to the normalized indicator values. The weighting score is determined individually for each indicator. Indicator weighting step enables taking relevant effects of each indicator to the vulnerability into consideration. One of two ways of weighting are commonly used, namely using either equal weights or unequal ones. Assigning equal weights to all indicators means that all indicators are considered equal in importance to the final index, whereas assigning unequal weights means that some indicators are higher or lower than other indicators in importance to the final index [26]. The most common unequal weighting methods to determine the weights are Deplhi and AHP [26], [27].

3.4 Vulnerability Index Computation

After all indicators have been normalized in between 0 and 1, for every AGEB, the social, economic, and physical vulnerability components (Vs, Ve, Vf) are computed as the arithmetical mean of the defining indicators (Zi). After all indicators have been normalized in between 0 and 1, each of exposure, vulnerability and resilience (Ve, Vs, Vr) from each vulnerability component are computed as the arithmetical mean of the defining indicator (FVI) in Equation:

$$V_{(e,s,r)} = \sum_{k=1}^{n} Z_k$$

The arithmetical approach in Equation (3) is the sum of the variable weight values of the sub-component indicator (Z_k). In this index computation, equal proportion of exposure, susceptibility, and resilience is assumed.

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

3.5 Interpretation of the Index Value

There are two approaches in interpreting the values of the FVI [24]. Fedeski & Gwilliam 2007; Kumar et al. 2010, in their studies evaluate the final index based on three classes: low vulnerability, moderate vulnerability, and high vulnerability. On the other hand, [8], [23], [28] classified it into five more detailed vulnerability classes, namely very low, low, moderate, high, and very high. Several studies use the range for the final index between 0 (very low vulnerability) to 1 (high and very high vulnerability) [28]–[30]. In the lights of two interpretation approach, we prefer categorization into five classes because it provides more details[31].

4. Results and Discussions

4.1 Selection of Relevant Indicators

Based on several studies, 18 indicators with numerical scales relevant to the study area are selected to compute FVI. The weights for the indicators are obtained by using Delphi combined with AHP by ensuring that Concistency Ratio (CR) value is less than 0.1 (Table 1). The weights of the normalized indicators show that total values of susceptibility, exposure, and resilience are 0.323, 0.455, and 0.256, respectively. There are five indicators for susceptibility, eight indicators for exposure, and five indicators for resilience, as shown in Table 1. Based on discussion with stakeholders, the selected indicators are suitable with the local condition.

Table 1. Parameter Values

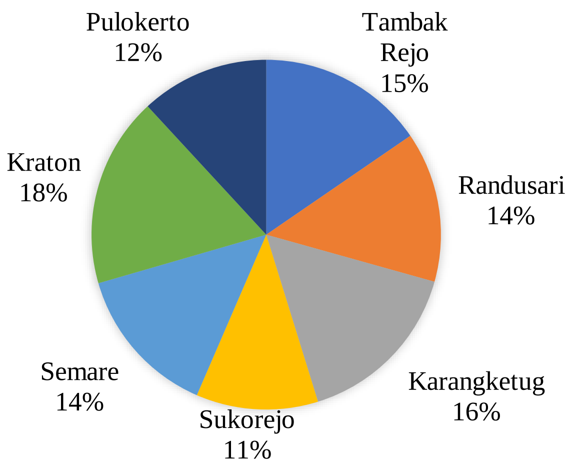
Vulnerability Factor	Indicator	Value	Reference
Susceptibility	Rainfall intensity	0.095	[9][8]
	Topographic	0.031	
	Closeness to the river	0.077	
	Type of soil	0.030	
	Tidal range	0.089	
Resilience	Level of education	0.056	[31]
	Experience with flood	0.058	[31]
	Knowledge about flood hazard	0.050	
	Knowledge about private protection measures	0.058	
	Income	0.033	[9], [32]
Exposure	Land use	0.090	[9][8]
	Age	0.028	[31]
	Gender	0.028	[8], [32]
	Main construction material for roof, walls and floor	0.075	[31]
	Position of buildings relative to the street level	0.066	
	Building density	0.037	[9], [32]
	Traffic density	0.064	
	Livelihood	0.034	

Source : Research document (2020)

102 - 109
ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

4.2 Selection of Relevant Indicators

Figure 3 present the flood exposure in each village. The values are distributed fairly evenly with the range between 11% to 18%. The largest exposure value is found in Katon village, and the smallest one is found in Sukorejo. The flood exposure will contribute highly to the vulnerability in cases of high use of productive land, high number of elderly residents and kids, high number of women, low capability of building structures, low elevation of buildings relative to the street level, high density of buildings, high traffic density, and high number of family members.



Source : Research document (2020)

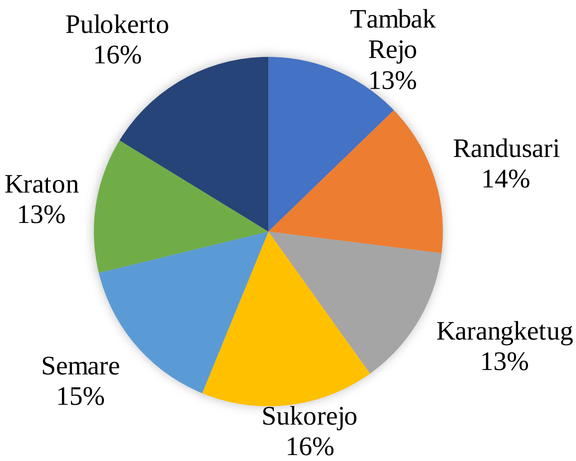
Figure 3. Proportion of The Exposure Value of Each Village

4.3 Flood Susceptibility

The flood susceptibility values are shown in Figure 4. Each of three villages, namely Kraton, Tambakrejo, dan Karangketug, has flood susceptibility value of 13%. Eah of two villages, namely Sukorejo dan Pulokerto, has the highest flood susceptibility value of 16%. The highest susceptibility index is affected by relatively high rainfall, relatively flat topography of the area, close distant of the houses to the river, low soil permeability, and high tidal wave. The natural indicators affecting susceptibility cannot be changed, but close distance to the river can be avoided by spatial planning to reduce the flood vulnerability.

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

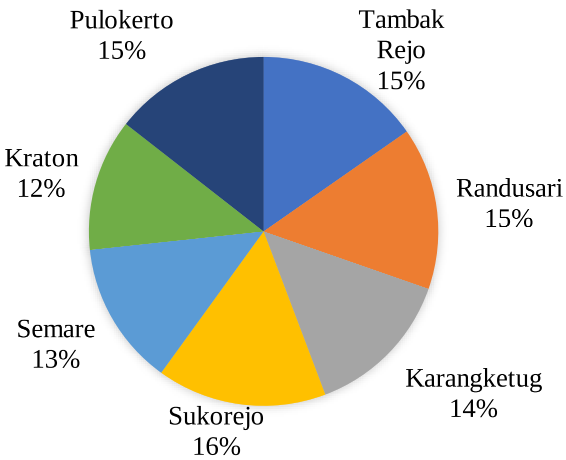


Source : Research document (2020)

Figure 4. Proportion of The Susceptibility Value of Each Village

4.4 Flood Resilience

The flood resilience values are shown in Figure 5. The range of the values is between 12% to 16%. Sukorejo is the villange with the highest resilience. Kraton is the village with the lowest resilience. The low resilience will worsen the flood vulnerability.



Source : Research document (2020)

Figure 5. The flood resilience value in each village

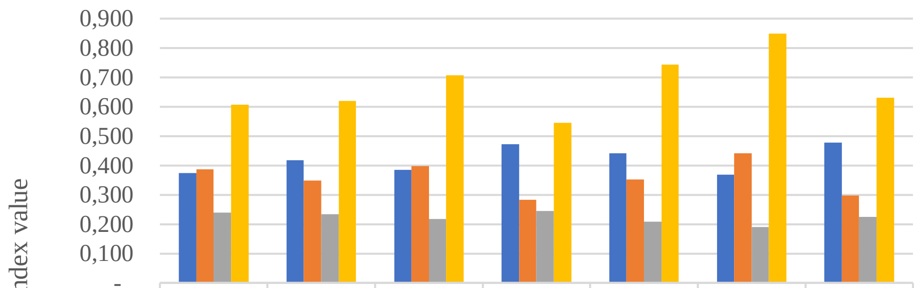
4.5 Analysis and Mapping of FVI

Figure 6 present the Flood Vulnerability Index computed as in Equation (1) by multiplying the exposure value with the susceptibility value divided by the resilience value, with the values presented in Figure 3, 4, and 5. Figure 7 shows very high vulnerability index in

http://dx.doi.org/10.30737/ukarst.v3i2

104 - 109
ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

Kraton village and high vulnerability indices in six other villages. The indices ordered from the highest to the lowest belong to Kraton, Semare, Karangketug, Pulokerto, Randusari, Tambakrejo dan Sukorejo. Figure 6 shows that Kraton has the highest vulnerability index, and Sukorejo has the lowest one. The high vulnerability of Kraton is because the resilience index in this village is the lowest among the seven villages whereas the exposure index is the highest. On the contrary, Sukorejo has the lowest vulnerability index because its exposure is low and its resilience is high even though its susceptibility index is high. It can be emphasized that the vulnerability index is mainly affected by the indices of the two factors.



	Tambak Rejo	Randusari	Karangketug	Sukorejo	Semare	Kraton	Pulokerto
Susceptibility	0,375	0,417	0,385	0,472	0,441	0,368	0,477
Ekposure	0,387	0,349	0,398	0,283	0,351	0,441	0,298
Resilience	0,239	0,235	0,217	0,245	0,208	0,191	0,225
Vulnerability	0,608	0,619	0,706	0,545	0,744	0,850	0,630

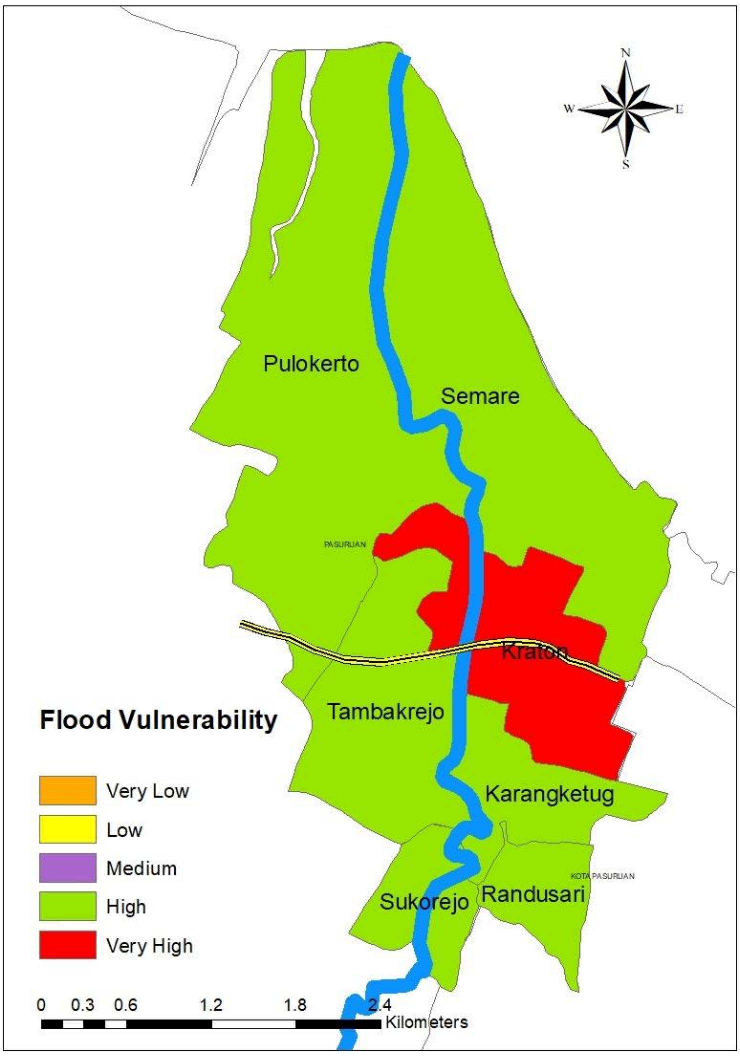
Source : Research document (2020)

Figure 6. The flood vulnerability Indices

The mean of resilience indices (0.223) is the lowest compared to the mean of susceptibility indices (0.419) and the mean of exposure indices (0.358). Based on the results, a possible step to minimize the vulnerability is to increase the local resilience capacity. It is important to encourage participation of local stakeholders such as individuals, households, family, and community groups in developing the skill and resources to build resilience in order to reduce the vulnerability to floods. It is also important to reduce the exposure through spatial planning and infrastructure regulation.

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620



Source : Research document (2020)

Figure 7. Flood Vulnerability Index

http://dx.doi.org/10.30737/ukarst.v3i2

106 - 109
ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

5. Conclusion and Suggestion

5.1 Conclusion

Based on the parameter selection results, the analysis and interpretation of the vulnerability indices as function of exposure, susceptibility, and resilience factors in the floodplain of Kali Welang, the following conclusion can be drawn.

There are eighteen parameters that affect the vulnerability index in the lowest part of Kali Welang. They consist of six parameters for exposure (rainfall intensity, topographic, closeness to the river, main construction material for roof, walls and floor, position of buildings in relation to the street level, and building density), nine parameters for susceptibility (land use, type of soil, tidal range, age, gender, level of education, traffic density, income, dan livelihood), and three parameters for resilience (experience with flood, knowledge about flood hazard, and knowledge about private protection measures).

The mean of resilience indices is the lowest (0.223) compared to the mean of susceptibility indices (0.419) and the mean of exposure indices (0.358).

The computation of the Flood Vulnerability Index results show that the vulnerability index varies between 0.545 to 0.850. The level of vulnerability is high in each of six villages and very high in Kraton village.

5.2 Suggestion

To reduce the flood vulnerability, a possible policy is to increase the capacity of the community in anticipating the floods and to reduce the indicators that affect the flood exposure in areas with high exposure indices.

http://dx.doi.org/10.30737/ukarst.v3i2

ISSN (*Online*) 2581-0855
ISSN (*Print*) 2579-4620

References

[1] B. Smit and J. Wandel, “Adaptation, adaptive capacity and vulnerability,” *Glob. Environ. Chang.*, vol. 16, no. 3, pp. 282–292, 2006, doi: 10.1016/j.gloenvcha.2006.03.008.

[2] A. Fekete, G. Hufschmidt, and S. Kruse, “Benefits and Challenges of Resilience and Vulnerability for Disaster Risk Management,” *Int. J. Disaster Risk Sci.*, vol. 5, no. 1, pp. 3–20, 2014, doi: 10.1007/s13753-014-0008-3.

[3] S. F. Balica, N. Douben, and N. G. Wright, “Flood vulnerability indices at varying spatial scales,” *Water Sci. Technol.*, vol. 60, no. 10, pp. 2571–2580, 2009, doi: 10.2166/wst.2009.183.

[4] J. Kim and T. H. T. Gim, “Assessment of social vulnerability to floods on Java, Indonesia,” *Nat. Hazards*, vol. 102, no. 1, pp. 101–114, 2020, doi: 10.1007/s11069-020-03912-1.

[5] S. F. Balica, “Development and Application of Flood Vulnerability Indices for Various Spatial Scales,” *M.Sc Thesis*, no. April, p. 157, 2007.

[6] L. G. Zachos, C. T. Swann, M. S. Altinakar, M. Z. McGrath, and D. Thomas, “Flood vulnerability indices and emergency management planning in the Yazoo Basin, Mississippi,” *Int. J. Disaster Risk Reduct.*, vol. 18, pp. 89–99, 2016, doi: 10.1016/j.ijdrr.2016.03.012.

[7] C. Salazar-Briones, J. M. Ruiz-Gibert, M. A. Lomelí-Banda, and A. Mungaray-Moctezuma, “An integrated urban flood vulnerability index for sustainable planning in arid zones of developing countries,” *Water (Switzerland)*, vol. 12, no. 2, 2020, doi: 10.3390/w12020608.

[8] H. Nasiri, M. J. M. Yusof, T. A. M. Ali, and M. K. B. Hussein, “District flood vulnerability index: urban decision-making tool,” *Int. J. Environ. Sci. Technol.*, vol. 16, no. 5, pp. 2249–2258, 2019, doi: 10.1007/s13762-018-1797-5.

[9] R. Mani Murali, M. Ankita, S. Amrita, and P. Vethamony, “Coastal vulnerability assessment of Puducherry coast, India, using the analytical hierarchical process,” *Nat. Hazards Earth Syst. Sci.*, vol. 13, no. 12, pp. 3291–3311, 2013, doi: 10.5194/nhess-13-3291-2013.

[10] L. Tascón-González, M. Ferrer-Julià, M. Ruiz, and E. García-Meléndez, “Social vulnerability assessment for flood risk analysis,” *Water (Switzerland)*, vol. 12, no. 2, 2020, doi: 10.3390/w12020558.

[11] M. Arifin, “8.740 Rumah di 9 Desa/Kelurahan di Pasuruan Terendam Banjir,” *news.detik.com*, 2018. .

[12] S. Balica and N. G. Wright, “Reducing the complexity of the flood vulnerability index,” *Environ. Hazards*, 2010, doi: 10.3763/ehaz.2010.0043.

ISSN (*Online*) 2581-2157
ISSN (*Print*) 2502-9304

[13] S. F. Balica, N. G. Wright, and F. van der Meulen, *A flood vulnerability index for coastal cities and its use in assessing climate change impacts*, vol. 64, no. 1. 2012.

[14] M. Vojtek and J. Vojteková, "Flood susceptibility mapping on a national scale in Slovakia using the analytical hierarchy process," *Water (Switzerland)*, vol. 11, no. 2, 2019, doi: 10.3390/w11020364.

[15] D. A. Arif, S. R. Giyarsih, and D. Mardiatna, "Kerentanan Masyarakat Perkotaan terhadap Bahaya Banjir di Kelurahan Legok, Kecamatan Telanipura, Kota Jambi," *Maj. Geogr. Indones.*, vol. 31, no. 2, p. 79, 2017, doi: 10.22146/mgi.29779.

[16] R. Mind *et al.*, "Flood susceptibility modeling and hazard perception in Rwanda," *Int. J. Disaster Risk Reduct.*, no. June, p. 101211, 2019, doi: 10.1016/j.ijdrr.2019.101211.

[17] C. S. Holling, "of Ecological Systems," *Source Annu. Rev. Ecol. Syst.*, vol. 4, no. 1973, pp. 1–23, 1973.

[18] M. Pelling, "The Vulnerability of Cities Natural Disasters and Social Resilience." Earthscan, 2003.

[19] O. Rahmati, H. Zeinivand, and M. Besharat, "Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis," *Geomatics, Nat. Hazards Risk*, vol. 7, no. 3, pp. 1000–1017, 2016, doi: 10.1080/19475705.2015.1045043.

[20] S. Samanta, D. K. Pal, and B. Palsamanta, "Flood susceptibility analysis through remote sensing, GIS and frequency ratio model," *Appl. Water Sci.*, vol. 8, no. 2, pp. 1–14, 2018, doi: 10.1007/s13201-018-0710-1.

[21] I. Emovon, "Ship System Maintenance Strategy Selection Based on DELPHI-AHP-TOPSIS Methodology," *World J. Eng. Technol.*, vol. 04, no. 02, pp. 252–260, 2016, doi: 10.4236/wjet.2016.42024.

[22] T. L. Saaty, "How to make a decision: The analytic hierarchy process," *Eur. J. Oper. Res.*, 1990, doi: 10.1016/0377-2217(90)90057-I.

[23] Y. Wang, Z. Li, Z. Tang, and G. Zeng, "A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China," *Water Resour. Manag.*, vol. 25, no. 13, pp. 3465–3484, 2011, doi: 10.1007/s11269-011-9866-2.

[24] M. Fedeski and J. Gwilliam, "Urban sustainability in the presence of flood and geological hazards: The development of a GIS-based vulnerability and risk assessment methodology," *Landsc. Urban Plan.*, vol. 83, no. 1, pp. 50–61, 2007, doi: 10.1016/j.landurbplan.2007.05.012.

[25] G. Naumann, P. Barbosa, L. Garrote, A. Iglesias, and J. Vogt, "Exploring drought vulnerability in Africa: An indicator based analysis to be used in early warning systems," *Hydrol. Earth Syst. Sci.*, vol. 18, no. 5, pp. 1591–1604, 2014, doi: 10.5194/hess-18-1591-2014.

Ukarst : Universitas Kadiri Riset Teknik Sipil. ISSN (*Online*) 2581-0855
Volume 5 Number 1, (2021). ISSN (*Print*) 2579-4620

[26] S. Rashetnia, "Flood Vulnerability Assessment by Applying a Fuzzy Logic Method : A Case Study from Melbourne By Samira Rashetnia," no. August, 2016.

[27] H. Nasiri, M. J. Mohd Yusof, and T. A. Mohammad Ali, "An overview to flood vulnerability assessment methods," *Sustain. Water Resour. Manag.*, vol. 2, no. 3, pp. 331–336, 2016, doi: 10.1007/s40899-016-0051-x.

[28] S. F. Balica, I. Popescu, L. Beevers, and N. G. Wright, "Parametric and physically based modelling techniques for flood risk and vulnerability assessment: A comparison," *Environ. Model. Softw.*, vol. 41, pp. 84–92, 2013, doi: 10.1016/j.envsoft.2012.11.002.

[29] M. Baučić, "Household level vulnerability analysis-index and fuzzy based methods," *ISPRS Int. J. Geo-Information*, vol. 9, no. 4, 2020, doi: 10.3390/ijgi9040263.

[30] K. Kantamaneni, M. Phillips, T. Thomas, and R. Jenkins, "Assessing coastal vulnerability: Development of a combined physical and economic index," *Ocean Coast. Manag.*, vol. 158, no. March, pp. 164–175, 2018, doi: 10.1016/j.ocecoaman.2018.03.039.

[31] A. Müller, J. Reiter, and U. Weiland, "Assessment of urban vulnerability towards floods using an indicator-based approach-a case study for Santiago de Chile," *Nat. Hazards Earth Syst. Sci.*, vol. 11, no. 8, pp. 2107–2123, 2011, doi: 10.5194/nhess-11-2107-2011.

[32] U. Budi and Supriharjo RD, "Pemintakatan Risiko Bencana Banjir Bandang di Kawasan Sepanjang Kali Sampean, Kabupaten Bondowoso," *J. Tek. ITS*, vol. 1, no. Vol 1, No 1, pp. C58–C62, 2012.