International Journal on Advanced Science Engineering Information Technology

Vol.14 (2024) No. 1
ISSN: 2088-5334

Flood Vulnerability and Resiliency in Coastal Areas Based on Geographic Information Systems (GIS) and Dynamic

Retno Tri Nalarsih [a,*], Henny Herawati [b], Eny Dyah Yuniwati [c], M. Adri Budi Sulistyo [c], Taufikkurrahman [d], Mudjiastuti Handajani [e]

[a] *Civil Engineering Department, Veteran Bantara Sukoharjo University, Sukoharjo, 57521, Indonesia*
[b] *Civil Engineering Department, Tanjungpura University, Jl. Prof. Dr.Hadari Nawawi Pontianak, 78124, Indonesia*
[c] *Agrotechnology Department, Faculty of Agriculture, Wisnuwardhana University, Malang, 65154, Indonesia*
[d] *Civil Engineering Department, Faculty of Engineering, Wisnuwardhana University, Malang, 65154, Indonesia*
[e] *Civil Engineering Department, Faculty of Engineering, Semarang University, Semarang, 50196, Indonesia*

*Corresponding author: *retno_nalarsih@univetbantara.ac.id*

***Abstract*—Floods are a disaster that is very detrimental and has an extensive impact, so it needs to be managed. GIS conducted this research and a dynamic system to model flood hazards and vulnerabilities in Kijang, Bintan City, and analyze flood hazards and vulnerabilities, so the purpose of this research is to map Flood Vulnerability and Resilience in Coastal Areas. The method used in this research is the Qualitative Descriptive method. Qualitative Descriptive Analysis of Survey Data and Interviews with the Community The interview data is used to validate the flood hazard analysis. Superimpose analysis using GIS, resulting in the condition of each indicator. To obtain the infiltration map, rainfall data processing, contour maps, and soil type maps are needed. Using weighting and scoring, vulnerability analysis was then analyzed, resulting in a flood-prone map. The results of this study show that high inundation caused by uncontrolled land use and flood hazards strongly influences flood proneness when the regulations are implemented or adhered to. Scenarios 1 and 2 from human resources analyzed the policy's application of Regional Regulations, which significantly regulate land use control. Local regulations are vital in regulating land use control; therefore, less flood vulnerability will occur when implemented or adhered to. Contributed to the state of mind of local regulations by providing a clearer definition and understanding, the assessment will help develop detailed risk reduction, mitigation, and management plans in determining more appropriate flood resilience indicators for policymakers.**

***Keywords*—Floods; vulnerability; resilience; coastal zone; Geographic Information System (GIS); system dynamic.**

Manuscript received 29 Jul. 2023; revised 28 Dec. 2023; accepted 4 Jan. 2024. Date of publication 29 Feb. 2024.
IJASEIT is licensed under a Creative Commons Attribution-Share Alike 4.0 International License.

I. INTRODUCTION

Floods that occur not only in Indonesia, but also experienced by countries around the world, which is a disaster that is very detrimental and has a very broad impact, so it must be appropriately managed [1]. Major floods occurred in the Mediterranean region and the Ligurian Sea coast, namely Liguria, Tuscany and Sardinia, the effects of weather characteristics, ground effects, and urban expansion in the region resulting in changes in hydro-geomorphological dynamics [2]. These floods are expected to have a higher flood risk when sea level rise occurs [3], [4], his is triggered by rapid economic and social development, which is not accompanied by appropriate and sustainable water management measures [5].

Factors that cause flooding include slope, infiltration rate, soil type, and land use. According to [6], in creating a spatial database, the data describing the factors that cause flooding include topography, geology, soil [7]. According to [8], modeling uses 11 factors that affect flood levels, namely rainfall, rainfall duration, peak rainfall, the proportion of roads, forests, grasslands, water bodies and buildings, permeability, catchment area, and slope. These factors are the hydrological review factors of an area.

Another review of flood mitigation lies in water management, especially in the direction of policies in management is very necessary [9], and it is also very important to manage floods [10]. Flood management has been widely researched and evaluated by government agencies, academics, and the private sector. With good management, flood mitigation can be carried out in a participatory manner by the community [11].

Accurate flood vulnerability mapping can provide meaningful insights to support flood mitigation and management [12]–[14]. Vulnerability itself is a state of being weak to hazards from exposure to stresses associated with environmental and social change, from the absence of capacity to adapt [15]. The current phenomenon of vulnerability and unsustainable resource use is due to deforestation, biodiversity loss and pollution [16]–[19]. Vulnerability analysis is essential for assessing the risk of natural hazards, and provides insights into future needs in vulnerability assessment [20]. Flood vulnerability assessment is a highly appropriate method for improving resilience [21]–[24], and for assessing mitigation measures [25] with the benefit of better understanding vulnerability to the impacts of each influencing factor [26].

Resilience is the ability to deal with disasters by having a system that is higher than the disaster risk. Post-flood resilience assessment aims to determine the impact of flooding in the area, the duration needed to recover, the development of a holistic framework for measuring security and resilience can be used by government authorities and development partners in planning and implementing mitigation and preparedness activities to manage and reduce hazard risks [27], it encourages the emergence of humans as a trigger, so that SDMs are placed as controllers and preparedness, assess changes over time, and build resilient communities [28].

Mapping using Geographic Information Systems (GIS) is needed to make it clearer, faster and thematic. Vulnerability mapping is an effective way to identify areas, the resulting flood hazard area maps identify areas and settlements at high risk of flooding [12], [14], [29], [30], using GIS with Extensive Classification to define four major classes in the study area, including (i) water bodies, (ii) agricultural land, (iii) barren and urban land, and (iv) dense forest, in order to monitor land use change and its future prospects [31]. GIS software are used to simulate land use changes, land-use projections, accessibility trends to infrastructure, natural resources [32].

Methods are needed to forecast the occurrence of disasters, especially floods, precisely to detect and predict information related to disasters and can minimize damage and more casualties [33]. According to [34], System Dynamics (SD) is a simulation modelling approach that represents the structure of complex systems through material and information feedback loops formed around stocks, flows, and additional variables. Systems thinking and soft operations research can help organize and guide the group processes that must occur when system dynamics interacts with people in actual systems. System dynamic models are useful in capturing complex human nonlinear effects on environmental systems [35].

Studies are conducted with dynamic, resilience-centered simulation models that provide a holistic representation of system components, various multi-hazard scenarios [36], SDMs work as managers who can implement appropriate strategies and policies in a timely manner to improve sustainability, being able to know what specific policies to use to add, adjust, or subtract [37]. Site-based assessments are effective for evaluating community performance over time and for decision makers, integrating resilience thinking into planning [38], but so far it is unclear the regulatory role used by stakeholders [39]. While results show that the proposed resource model is effective for risk assessment, management, and uncertain decision [40].

Using hydrodynamic optimization models as a useful decision-making tool in visualizing trade-offs among flood management strategies [41]. So that it is sustainable [42], based on the resilience of several components with nonlinear interdependencies [36]. A holistic approach that integrates three indicators of social, economic, and institutional resilience, social and spatial interactions [43], and ecological environmental resilience [44].

This research was conducted by collaborating between Geographic Information System (GIS) and Dynamic System in modeling flood hazard and vulnerability in Kijang, Bintan City. Flooding is expected every time it rains heavily, causing high inundation. There are indications of high flood vulnerability with predictions of uncontrolled land use, so it is necessary to analyze flood hazards and vulnerability in real time to make a clearer map of existing conditions with policy direction analysis.

II. Materials and Methods

A. Description of The Study Area

The research was conducted in Kijang Kota Urban Village, East Bintan District 0° 56' 15" to 104° 33' 29" North latitude and 0° 48' 25" to 104° 35' 30" North latitude and Bintan Regency. Kijang City Kota was chosen because it has a diverse geomorphology, and has highland, lowland and coastal characteristics. Administratively according to Fig. 1.

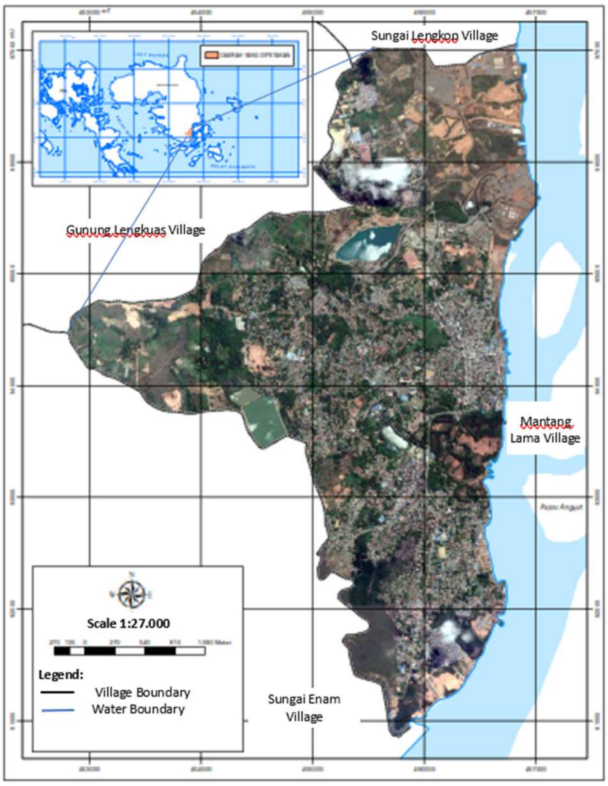

Fig.1 Location of the study Area, Bintan Timur Subdistrict, Indonesia

Kijang Kota Village is the smallest of the villages in East Bintan Sub-district with an area of 23.91 km2. This location was chosen because based on the survey, the location has a high flood vulnerability that needs to be studied for annual flood trigger variables.

B. Data and Methods

1) Primary data: It was collected from interviews on flood events with experts, namely BAPPEDA, the Environment Agency, the Riau Islands Central Statistics Agency (BPS), and local communities, then validated with data from the inventory of flood inundation, according to Fig. 2.

Fig. 2 Flood Inundation Height Location, Documentation 2021

Figure 2 shows that the inundation height was 160 cm, and the inundation occurred along the upstream channel towards the downstream as high as 90 cm.

2) Secondary Data: Annual rainfall data from BPS, processed to include infiltration calculations then to mapping. Physical vulnerability was conducted using GIS analysis. 5 (Five) types of land use were identified namely, building land has an area of 531.2 Ha, vacant land 111.7 Ha, water 96.7 Ha, and shrubs 306.7 Ha.

C. Research Instruments and Data Analysis Methods

The instruments used in the research are hardware consisting of PC Computers and Printers. Software consists of ArcGIS 10 software, Microsoft Word, Anylogic software, excel and Digital Camera. Data analysis was carried out as follows:

1) Qualitative Descriptive Analysis. The data from surveys and interviews with the community were used to validate the flood hazard analysis. Validation of data obtained from GIS data processing. Variables are topography, land use or land use, slope, rainfall, soil type, and flood hazard.

2) Superimpose Analysis: This analysis used GIS, resulting in the condition of each indicator. In order to obtain the infiltration map, it is necessary to process rainfall data, contour maps, soil type maps. Overlay analysis approach using Geographic Information System (GIS) according to the procedure in Fig. 3.

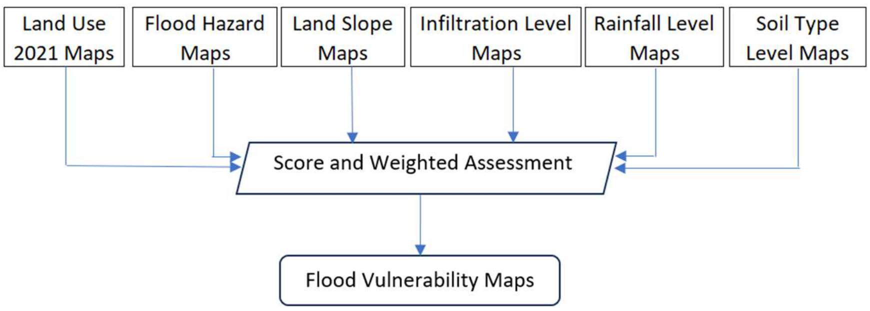

Fig. 3 GIS Flow Chat for Flood Prone Map Preparation

Fig. 3 shows the results of flood vulnerability, flood hazard zone identification, and field data to identify potential hazard zones. Vulnerability analysis using weighting and scoring, then analyzed, resulting in a flood prone map [45]. The results of scoring, weighting, and parameter scoring are for flood hazard and infiltration rate (high, medium, and low), slope 0 to 10, 10 to 20, 20 to 30, 30 to 40, and greater than 40 with the highest value 6 lowest 1. Very high rainfall with a value of 5, high with a value of 4, medium with a value of 3, low with a value of 2, and very low with a value of 1. Landuse water with a value of 5, vacant land with a value of 4, buildings with a value of 3. Shrubs with a value of 2, and forest with a value of 1. Soil type characteristics are fine with a value of 5, rather fine with a value of 4, medium with a value of 3, rather coarse with a value of 2, and coarse with a value of 1.

3) System Dynamics Model (SDM): Systems Dynamic provides an understanding and as a tool to help make decisions, so that the level of regulation in reducing flood vulnerability is known and how long it takes to reach flood resilience conditions. The system dynamics approach is used to make it easier to see the factors that influence flood management and prevention, with the intervention of local government regulations as policy direction, built with the Causal Loop Diagram (CLD) in Fig. 4.

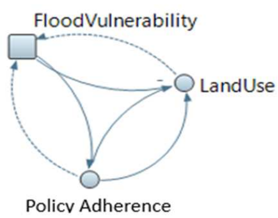

Fig.4 CLD of local regulations on disaster vulnerability

Fig. 4 explains the basic form of the dynamic system, the magnitude of the application of local regulations that have an impact on land use as a catchment area, on disaster vulnerability. Based on Figure 4, it can be divided into three sub models, namely the land use sub model, the disaster vulnerability sub model, and the policy implementation sub model, related to controlling land use and disaster vulnerability. The next stage constructed CLD two, according to Fig. 5.

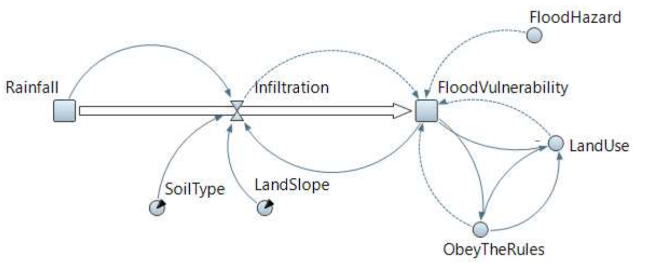

Fig. 5 Open Causal Flood Vulnerability Dynamical System Model

Fig. 5 shows the CLD of the physical submodel, explaining that the infiltration submodel is the effect of rainfall, soil type, and slope. The disaster-prone submodel is the effect of the infiltration, flood hazard, land use, and Per-Da submodels. The overall loop is strongly intervened by the application of Per-Da in minimizing the impact of land use and disaster prone. This is highly relevant to the solutions generated from the expert discussions. . It supports the next analysis by using policy as a dynamic system variable.

The next stage based on information from literature and related research analyzes the theories, do to expand the boundaries and model the variables endogenously. This stage aims to describe the height of flood vulnerability using a system dynamics approach. Validity construction is performed on each variable and sub model. The validity process is carried out by entering the reference of each variable. There is an initial model of flood prone sub-models, policies in the form of Per-Da and land use. Next, it is constructed with the infiltration sub-model, thus obtaining an open causal model, illustrating that both sub-models get an effect condition from each sub-model.

III. Results and Discussion

A. Results of Kijang Kota Village Profile Analysis

Primary data analysis of geological conditions of rock types is mostly Goungon Formation and Granite. The dominance of the goungon formation is approximately 65% which is evenly distributed, there is also Andesite and Aluvium, which has a very low water absorption character, so this affects the length of inundation. Located at an altitude of 36 m DPL. The dominant slope of 0 to 3% indicates a relatively flat topography, making it vulnerable to inundation conditions. Climatological conditions show an average temperature of 28 C°, an average wind speed of 30 to 40 Km/day, analyzed to find the monthly average from 2016 to 2020 that the highest Daily Maximum Rainfall occurs in June and July, and this is in accordance with flooding events that occur between June and July.

B. GIS Superimpose Analysis

The results of the superimpose analysis based on the weighting and ranking classification found that the flood hazard was 20%, the infiltration rate was 20%, the slope was 10%, the rainfall was 20%, the land use was 20%, the soil texture was 10%. This shows that the parameters of flood hazard, infiltration rate, rainfall, and land use have the same influence of 20%.

The analysis of rainfall is based on the classification of very high with a score of 5, high with a score of 4, medium with a score of 3, low with a score of 2, and very low with a score of 1. Analysis in the form of Geographic Information System (GIS) results analysis according to Fig. 6.

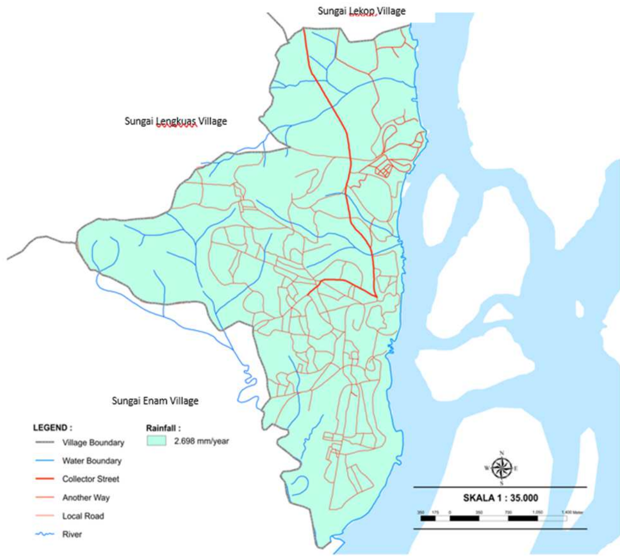

Fig. 6 Rainfall Map of Kijang Kota Urban Village

Based on Figure 6, that the analysis obtained 20%, which means that the effect of rainfall on prone to flooding is 20% of all parameters used. In accordance with the mapping results that rainfall is 2000 mm / year, with an even distribution. Compiled slope map attached in Figure 7.

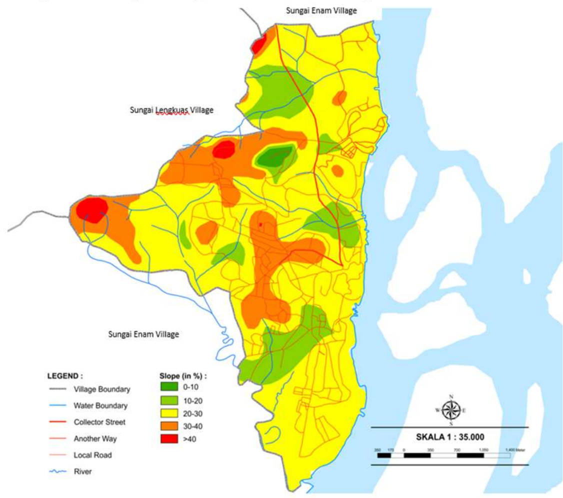

Fig. 7 Slope Map of Kijang Kota Village

Using the classification of slope 0 to 10 is worth 6, slope 10 to 20 is worth 5, slope 20 to 30 is worth 4, slope 30 to 40 is worth 2, slope more than 40 is worth 1. The results show 10%, meaning that the slope affects flood prone by 10%. Fig. 7 shows the lowest slope is around the coast. Further analysis of slope to area resulted in a slope of 0 to 10 having an area of 8.2 Ha, a slope of 10 to 20 having an area of 160.8 Ha, a slope of 20 to 30 having an area of 803.6 Ha, a slope of 30 to

40 having an area of 201.8 Ha, and a slope greater than 40 having an area of 19.7 Ha. The analysis shows that land with a slope between 20 and 30 is the largest land area, followed by a slope of 30 to 40 and a slope greater than 40.

This means that the Kelurahan Kijang Kota area geographically tends to be difficult to retain water, because there is very little land surface that can be used to retain water, so that water from upstream goes directly to the lower area as a catchment area. Classification based on fine soil texture with a score of 5, rather fine 4, medium 3, rather coarse 2, and coarse score 1. The resulting weighting of 10% means that soil texture has a 10% influence on flood proneness.

Fig. 8 Soil Type Map of Kelurahan Kijang Kota

Fig. 8 shows that soil types tend to be the same, namely podzolic which has compact sand, sand, and clay sand material and is composed of an unconfined aquifer system, which does not absorb water easily. It is also said that the soil fertility of open pit bauxite mines is lower than that of natural forests in Indonesia. Organic carbon concentrations are also lower in open bauxite mine land than in natural forests [46], meaning the soil has very poor conditions for infiltration.

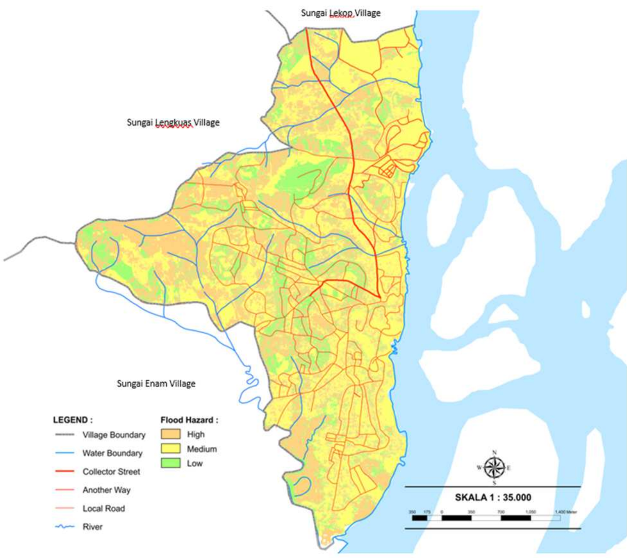

Fig. 9 Infiltration Level Map

Based on the analysis of infiltration rate, the low condition is 194.1 ha, the medium condition is 545.9 ha, and the high condition is 452.9 ha. Slope more than 40% has an area of 19.7, 30 to 40 has an area of 201.8 Ha, 20 to 30 has an area of 803.6 Ha, 10 to 20 has an area of 160.8 Ha, 0 to 10 has an area of 8.3 Ha. The results of the land use analysis of buildings have an area of 531.2 Ha, forest 152.1 Ha, vacant land 111.7 Ha, water 96.7 Ha, shrubs 306.7 Ha. The infiltration level map is shown in Fig. 9.

The analysis was carried out on the results of weighting with a high classification with a score of 3, medium with a score of 2, and low with a score of 1. The results of the analysis show a weighting value of 20%, meaning that the level of infiltration has an influence of 20% on flood proneness in Kijang Kota Village.

The next analysis is the weighting based on land use (land use), the classification of waters with a score of 5, vacant land 4, buildings 3, shrubs 2, and forests 1. The results of the land use parameter weighting of 20%, indicate that land use has a 20% influence on flood proneness. Analysis of land use ranking on the area, which is shown on Figure 10, with the building classification has an area of 531.2 Ha, the forest classification has an area of 152.1 Ha, the vacant land classification has an area of 111.6 Ha, the water classification has an area of 96.7 Ha, and the shrub classification has an area of 306.7 Ha.

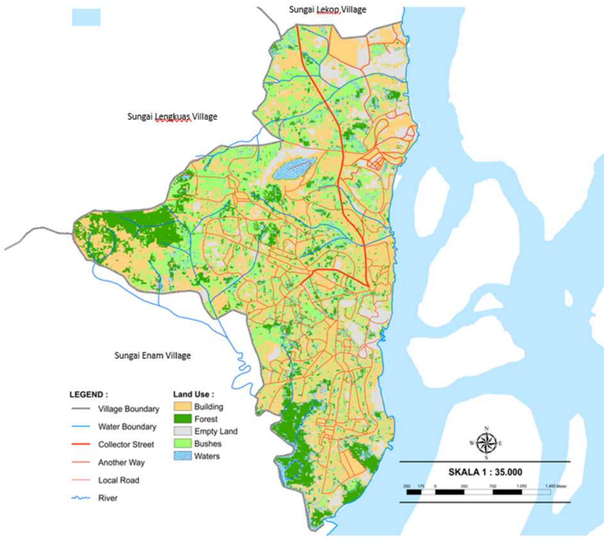

Fig. 10 Land Use Map

Based on Fig. 10. shows that land with building designation dominates land use, in accordance with the results of previous weighting and scoring. The location of land use for buildings and shrubs is located almost along the coast. The results of the analysis show that the building area has a donated land use area, followed by shrubs, and forests. This shows that the influence of land use has a great tendency to cause flooding.

C. Flood Hazard Analysis

The analysis of the weighting of flood hazards with a high classification gives a score of 3, medium 2, and low 1. The result is a weight of 20%, which indicates that flood hazards have an influence on the occurrence of flood vulnerability by 20% of all parameters used, attached Figure 11.

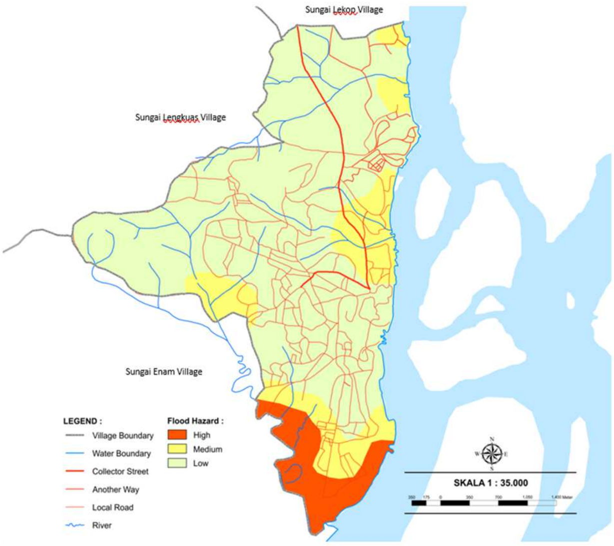

Fig. 11 Flood Hazard Map

Figure 11 shows that the analysis of flood hazards based on area, namely the classification of low flood hazard areas has an area of 907.65 Ha, medium 197.11 Ha, and high hazard 93.94 Ha. The results of the analysis show that the dominant low flood hazard is on slopes between 10 to 20 degrees in the form of inundation, while the medium hazard is on the coastal part of the Daik River estuary in the form of flooding due to back water, and the high hazard is located in the coastal area of the Enam River area, Tokojo Harbor, and the Tokojo Gas Engine Power Plant (PLTMG) environment.

D. Flood Vulnerability Analysis

The results of the flood vulnerability analysis based on the area are arranged with low conditions having an area of 209.13 Ha, very low having an area of 13.05 Ha, very high having an area of 8.74 Ha, medium having an area of 679.06 Ha, and high having an area of 282.52 Ha. The analysis shows that moderate vulnerability has the largest area, followed by high conditions, and low conditions. The flood vulnerability map is shown in Fig. 12.

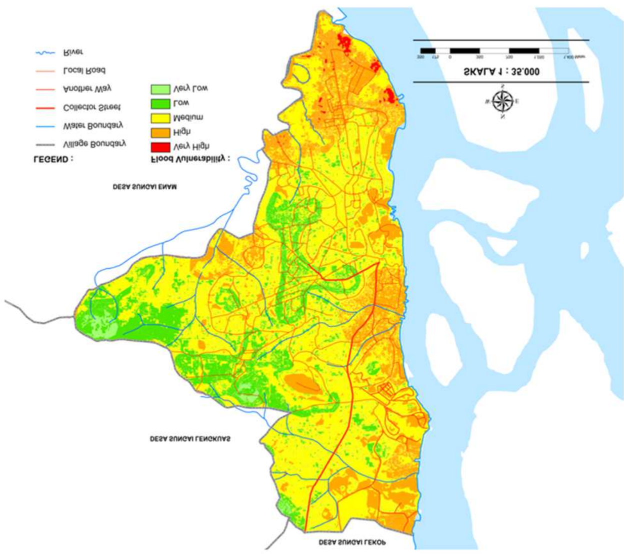

Fig. 12 Flood Vulnerability Map

Fig. 12 shows that areas with very high conditions are in the Enam River area, Tokojo Harbor, and the Tokojo Gas Engine Power Plant (PLTMG) environment, in the form of runoff flooding due to back water. High conditions spread in areas less than 10 degrees in the form of inundation flood plains due to high rainfall, moderate conditions dominate flood-prone conditions spread in slope areas between 10 and 20 degrees indicated due to inundation flooding, low on slopes of 20 to 30 and very low conditions on slopes of 30 to 40.

Based on land use, in the form of buildings or built-up occupies the highest area of 44% of the total area, but with shrubs 26%, which has the second area, a direction can still be pursued based on the policies of the Riau Islands Province Regional Regulation, Number 1 of 2017, concerning the Regional Spatial Plan of Riau Islands Province, 2017-2037. So, this regulation will be used as a parameter for the next analysis. Policy direction for increasing flood resilience is based on the results of GIS, obtained identification of hazardous and flood-prone locations, the next stage we conduct an analysis to achieve flood resilience by compiling a dynamic system concept in Fig. 14.

E. Dynamic System Analysis as a Policy Direction for Increasing Flood Resilience

The solution uses Regional Regulation as a variable in the dynamic system, functioning as a land use control intervention, in order to create flood resilience conditions. The result of System Dynamics Model (SDM) is attached as Fig. 13.

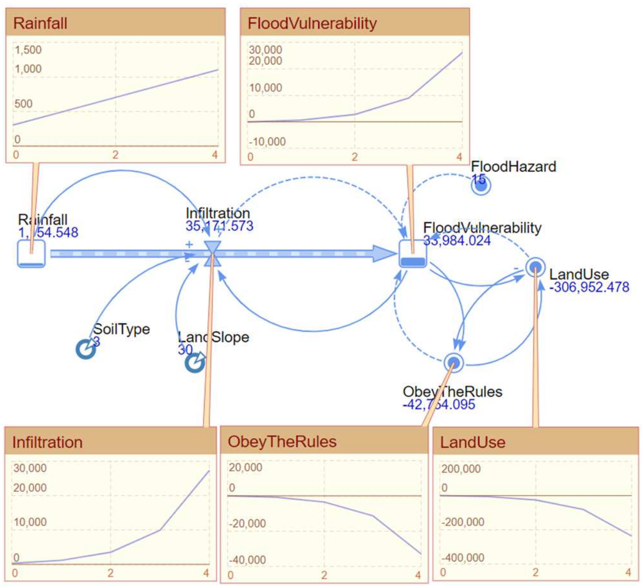

Fig. 13 Scenario 1

Figure 13 shows that the scenario in year 1 (First) of the Regional Regulation (Per-Da) was implemented, the rainfall scenario increased, resulting in an increase in land use area, resulting in increased infiltration, and successfully reducing disaster prone areas. But during year 2 (two), with the Per Da scenario starting to be disobeyed, and rainfall increasing, there was a decrease in the area of water-capturing land, infiltration began to stabilize, and disaster prone began to increase. Furthermore, it was constructed again, with a different scenario according to Fig. 14.

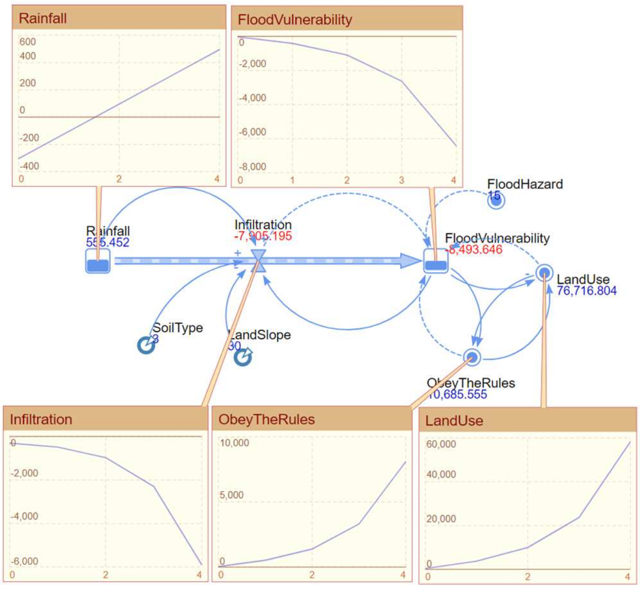

Fig. 14 Scenario 2

Based on Fig. 14, it shows that the scenario analyzed within 10 (ten) years, although soil infiltration is scenario to decrease, but disaster vulnerability may decrease because Per Da (Governor's regulation) is strictly implemented, so that land use increases. The modeling results of scenarios 1 and 2 analyzed according to Figures 12 and 13 show the dynamic system in the loop, analyzed rainfall conditions are considered to be increasing in the first 3 years. The Regional Regulation began to be implemented and experienced a reduction in violations in the first year to the next 3 years, although infiltration was getting smaller, it had an impact on increasing land use as a catchment area and reducing flood vulnerability.

IV. Conclusion

The data from the expert interview and survey, resulted in the initial characteristic that the location occurs flooding with high inundation caused by uncontrolled land use. The results of the flood hazard analysis show that the dominant low flood hazard is on slopes between 10 to 20 degrees in the form of inundation, medium hazard is on the coastal part of the Daik River estuary in the form of flooding due to back water, and high hazard is located in the coastal area of the Enam River area, Tokojo Harbor, and the Tokojo Gas Engine Power Plant (PLTMG) environment.

The results of the flood vulnerability analysis show areas with very high conditions are located in the Sungai Enam, Tokojo Harbor, and Tokojo Gas Engine Power Plant (PLTMG) areas, in the form of runoff flooding due to back water. High conditions spread in areas less than 10 degrees in the form of inundation flood plains due to high rainfall, moderate conditions dominate flood-prone conditions scattered in the slope area between 10 to 20 degrees indicated due to inundation flooding, low on slopes of 20 to 30 and very low conditions on slopes of 30 to 40.

Based on the above two points, a policy direction was prepared with the intervention of the application of the current Per-Da, analyzed by SDM, resulting in scenarios 1 and 2 that the application of policies in the form of Regional Regulations plays a very important role in regulating land use control, so that the more Per-Da is applied or adhered to, the less flood vulnerability will occur. This study has contributed to the gap in the role of Per Da in providing a clearer definition and understanding, such an assessment will help develop detailed risk reduction, mitigation and management plans, assisting in determining more appropriate flood resilience policy development indicators. This research recommends that the full involvement of policy makers in the development of model policies and cooperative strategies to mitigate and strengthen adaptation to disaster risks.

Acknowledgements

The authors thank CV Citrawees Salawasna for giving us the opportunity to participate in the site survey in obtaining primary data.

AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

References

[1] M. Chen *et al.*, "A flood predictability study for Hurricane Harvey with the CREST-iMAP model using high-resolution quantitative precipitation forecasts and U-Net deep learning precipitation nowcasts," *J. Hydrol.*, vol. 612, Sep. 2022, doi:10.1016/j.jhydrol.2022.128168.

[2] F. Faccini, F. Luino, G. Paliaga, A. Roccati, and L. Turconi, "Flash flood events along the west mediterranean coasts: Inundations of urbanized areas conditioned by anthropic impacts," *Land*, vol. 10, no. 6, 2021, doi: 10.3390/land10060620.

[3] V. Hadipour, F. Vafaie, and K. Deilami, "Coastal flooding risk assessment using a GIS-based spatial multi-criteria decision analysis approach," *Water (Switzerland)*, vol. 12, no. 9, 2020, doi:10.3390/W12092379.

[4] J. C. L. Normand, E. Heggy, and P. Castellazzi, "Nationwide Subsidence in Bahrain Island: Drivers and Implications for Relative Sea Level Rise," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. PP, pp. 1–17, 2023, doi: 10.1109/JSTARS.2023.3286471.

[5] X. Wang and H. Xie, "A review on applications of remote sensing and geographic information systems (GIS) in water resources and flood risk management," *Water (Switzerland)*, vol. 10, no. 5, May 2018, doi:10.3390/w10050608.

[6] V. Ayoub *et al.*, "A porosity-based flood inundation modelling approach for enabling faster large scale simulations," *Adv. Water Resour.*, vol. 162, Apr. 2022, doi: 10.1016/j.advwatres.2022.104141.

[7] X. Lei *et al.*, "Urban flood modeling using deep-learning approaches in Seoul , South Korea," *J. Hydrol.*, vol. 601, p. 126684, 2021, doi:10.1016/j.jhydrol.2021.126684.

[8] H. Wang, H. Wang, Z. Wu, and Y. Zhou, "Using multi-factor analysis to predict urban flood depth based on naive bayes," *Water (Switzerland)*, vol. 13, no. 4, 2021, doi: 10.3390/w13040432.

[9] R. D'Ambrosio and A. Longobardi, "Adapting drainage networks to the urban development: An assessment of different integrated approach alternatives for a sustainable flood risk mitigation in Northern Italy," *Sustain. Cities Soc.*, vol. 98, no. April, p. 104856, 2023, doi: 10.1016/j.scs.2023.104856.

[10] M. K. Webber and C. Samaras, "A Review of Decision Making Under Deep Uncertainty Applications Using Green Infrastructure for Flood Management," *Earth's Futur.*, vol. 10, no. 7, 2022, doi:10.1029/2021EF002322.

[11] H. Herawati and S. B. Soeryamassoeka, "Drought mitigation participatory at Pinang Luar Lowland, West Borneo (Indonesia)," *MATEC Web Conf.*, vol. 101, pp. 0–4, 2017, doi:10.1051/matecconf/201710104022.

[12] H. Desalegn and A. Mulu, "Mapping flood inundation areas using GIS and HEC-RAS model at Fetam River, Upper Abbay Basin, Ethiopia," *Sci. African*, vol. 12, Jul. 2021, doi: 10.1016/j.sciaf.2021.e00834.

[13] L. Menk, C. Neuwirth, and S. Kienberger, "Mapping the structure of social vulnerability systems for Malaria in East Africa," *Sustain.*, vol. 12, no. 12, 2020, doi: 10.3390/su12125112.

[14] F. N. Nkeki, E. I. Bello, and I. G. Agbaje, "Flood risk mapping and urban infrastructural susceptibility assessment using a GIS and analytic hierarchical raster fusion approach in the Ona River Basin, Nigeria," *Int. J. Disaster Risk Reduct.*, vol. 77, Jul. 2022, doi:10.1016/j.ijdrr.2022.103097.

[15] L. Quesada-Ganuza, L. Garmendia, E. Roji, and A. Gandini, "Do we know how urban heritage is being endangered by climate change? A systematic and critical review," *Int. J. Disaster Risk Reduct.*, vol. 65, Nov. 2021, doi: 10.1016/j.ijdrr.2021.102551.

[16] M. A. Martin *et al.*, "Ten new insights in climate science 2022," *Glob. Sustain.*, vol. 5, 2022, doi: 10.1017/sus.2022.17.

[17] J. Li, Z. Fang, J. Zhang, Q. Huang, and C. He, "Mapping basin-scale supply-demand dynamics of flood regulation service – A case study in the Baiyangdian Lake Basin, China," *Ecol. Indic.*, vol. 139, Jun. 2022, doi: 10.1016/j.ecolind.2022.108902.

[18] S. Ghaffarian, D. Roy, T. Filatova, and N. Kerle, "Agent-based modelling of post-disaster recovery with remote sensing data," *Int. J. Disaster Risk Reduct.*, vol. 60, no. August 2020, p. 102285, 2021, doi:10.1016/j.ijdrr.2021.102285.

[19] Z. Fang, Y. Wang, L. Peng, and H. Hong, "Predicting flood susceptibility using LSTM neural networks," *J. Hydrol.*, vol. 594, Mar. 2021, doi: 10.1016/j.jhydrol.2020.125734.

[20] M. Papathoma-Köhle *et al.*, "Physical vulnerability to dynamic flooding: Vulnerability curves and vulnerability indices," *J. Hydrol.*, vol. 607, Apr. 2022, doi: 10.1016/j.jhydrol.2022.127501.

[21] A. R. Hamidi, L. Jing, M. Shahab, K. Azam, M. A. U. R. Tariq, and A. W. M. Ng, "Flood Exposure and Social Vulnerability Analysis in Rural Areas of Developing Countries: An Empirical Study of Charsadda District, Pakistan," *Water (Switzerland)*, vol. 14, no. 7, 2022, doi: 10.3390/w14071176.

[22] F. Addona, F. Sistilli, C. Romagnoli, L. Cantelli, T. Liserra, and R. Archetti, "Use of a Raspberry-Pi Video Camera for Coastal Flooding Vulnerability Assessment: The Case of Riccione (Italy)," 2022, doi:10.3390/w14070999.

[23] D. Babanawo, P. A. D. Mattah, S. K. M. Agblorti, E. K. Brempong, M. M. Mattah, and D. W. Aheto, "Local Indicator-Based Flood Vulnerability Indices and Predictors of Relocation in the Ketu South Municipal Area of Ghana," *Sustain.*, vol. 14, no. 9, 2022, doi:10.3390/su14095698.

[24] U. P. Guragain and P. Doneys, "Social, Economic, Environmental, and Physical Vulnerability Assessment: An Index-Based Gender Analysis of Flood Prone Areas of Koshi River Basin in Nepal," *Sustain.*, vol. 14, no. 16, 2022, doi: 10.3390/su141610423.

[25] M. Kosič, A. Anžlin, and V. Bau', "Flood Vulnerability Study of a Roadway Bridge Subjected to Hydrodynamic Actions, Local Scour and Wood Debris Accumulation," *Water (Switzerland)*, vol. 15, no. 1, 2023, doi: 10.3390/w15010129.

[26] K. Kantamaneni *et al.*, "Towards a Combined Physical and Social Evaluation of Climate Vulnerability in Coastal Urban Megacities," *Water (Switzerland)*, vol. 15, no. 4, pp. 1–20, 2023, doi:10.3390/w15040712.

[27] I. Pal *et al.*, "Multi-Hazard Livelihood Security and Resilience of Lower Mekong Basin Communities," *Sustain.*, vol. 15, no. 11, 2023, doi: 10.3390/su15118469.

[28] Z. Adeel *et al.*, "Developing a comprehensive methodology for evaluating economic impacts of floods in Canada, Mexico and the United States," *Int. J. Disaster Risk Reduct.*, vol. 50, 2020, doi:10.1016/j.ijdrr.2020.101861.

[29] S. G. Manoharan and G. P. Ganapathy, "GIS based urban social vulnerability assessment for liquefaction susceptible areas : a case study for greater Chennai , India," *Geoenvironmental Disasters*, pp. 1–22, 2023, doi: 10.1186/s40677-022-00230-5.

[30] E. C. Chukwuma, C. C. Okonkwo, J. O. Ojediran, D. C. Anizoba, J. I. Ubah, and C. P. Nwachukwu, "A Gis Based Flood Vulnerability Modelling Of Anambra State Using An Integrated Ivfrn-Dematel-Anp Model," *Heliyon*, vol. 7, no. 9, Sep. 2021, doi:10.1016/j.heliyon.2021.e08048.

[31] M. T. Zeshan, M. R. U. Mustafa, and M. F. Baig, "Article monitoring land use changes and their future prospects using gis and ann-ca for perak river basin, malaysia," *Water (Switzerland)*, vol. 13, no. 16, 2021, doi: 10.3390/w13162286.

[32] A. Suriadikusumah, A. Mulyono, and M. H. R. Maulana, "Prediction of Bandung District Land Use Change Using Markov Chain Modeling," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 12, no. 1, pp. 237–243, 2022, doi: 10.18517/ijaseit.12.1.12384.

[33] A. Suharjono *et al.*, "MiSREd: A Low Cost IoT-Enabled Platform Based on Heterogeneous Wireless Network for Flood Monitoring," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 13, no. 3, p. 1137, 2023, doi:10.18517/ijaseit.13.3.18296.

[34] J. W. Forrester, "System dynamics, systems thinking, and soft OR," *Syst. Dyn. Rev.*, vol. 10, no. 2–3, pp. 245–256, 1994, doi:10.1002/sdr.4260100211.

[35] C. Leong, "The Role of Narratives in Sociohydrological Models of Flood Behaviors," *Water Resour. Res.*, vol. 54, no. 4, pp. 3100–3121, 2018, doi: 10.1002/2017WR022036.

[36] A. Badr, Z. Li, and W. El-Dakhakhni, "Dynamic Resilience Quantification of Hydropower Infrastructure in Multihazard Environments," *J. Infrastruct. Syst.*, vol. 29, no. 2, pp. 1–16, 2023, doi:10.1061/jitse4.iseng-2188.

[37] M. Hell and L. Petrić, "System dynamics approach to TALC modeling," *Sustain.*, vol. 13, no. 9, 2021, doi: 10.3390/su13094803.

[38] M. Moghadas, A. Asadzadeh, A. Vafeidis, A. Fekete, and T. Kötter, "A multi-criteria approach for assessing urban flood resilience in Tehran, Iran," *Int. J. Disaster Risk Reduct.*, vol. 35, no. 101069, pp. 1–14, Apr. 2019, doi: 10.1016/j.ijdrr.2019.101069.

[39] A. Pagano, I. Pluchinotta, P. Pengal, B. Cokan, and R. Giordano, "Engaging stakeholders in the assessment of NBS effectiveness in flood risk reduction: A participatory System Dynamics Model for benefits and co-benefits evaluation," *Sci. Total Environ.*, vol. 690, pp. 543–555, Nov. 2019, doi: 10.1016/j.scitotenv.2019.07.059.

[40] L. Liang, "A study of system dynamics modelling and optimization for food safety risk communication in China," *Alexandria Eng. J.*, vol. 60, no. 1, pp. 1917–1927, 2021, doi: 10.1016/j.aej.2020.11.039.

[41] A. Alves, Z. Vojinovic, Z. Kapelan, A. Sanchez, and B. Gersonius, "Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation," *Sci. Total Environ.*, vol. 703, p. 134980, 2020, doi: 10.1016/j.scitotenv.2019.134980.

[42] M. J. Keyhanpour, S. H. Musavi Jahromi, and H. Ebrahimi, "System dynamics model of sustainable water resources management using the Nexus Water-Food-Energy approach," *Ain Shams Eng. J.*, vol. 12, no. 2, pp. 1267–1281, 2021, doi: 10.1016/j.asej.2020.07.029.

[43] C. Heinzlef, V. Becue, and D. Serre, "Operationalizing urban resilience to floods in embanked territories – Application in Avignon, Provence Alpes Côte d'Azur Region," 2019. doi:10.1016/j.ssci.2019.05.003.

[44] W. Xu, Q. Yu, and D. Proverbs, "Evaluation of Factors Found to Influence Urban Flood Resilience in China," *Water (Switzerland)*, vol. 15, no. 10, pp. 1–24, 2023, doi: 10.3390/w15101887.

[45] T. Alharbi, "Mapping of Groundwater, Flood, and Drought Potential Zones in Neom, Saudi Arabia, Using GIS and Remote Sensing Techniques," *Water (Switzerland)*, vol. 15, no. 5, Mar. 2023, doi:10.3390/w15050966.

[46] R. Prematuri, M. Turjaman, T. Sato, and K. Tawaraya, "Post Bauxite Mining Land Soil Characteristics and Its Effects on the Growth of Falcataria moluccana (Miq.) Barneby & J. W. Grimes and Albizia saman (Jacq.) Merr.," *Appl. Environ. Soil Sci.*, vol. 2020, 2020, doi:10.1155/2020/6764380.