Analysis Geomorphic Flood Index in Determining Flood-Prone Areas in East Kalimantan Province, Indonesia

Riantini Virtriana[a,b,f,*], Annisa Fitri Amalia[c], Kalingga Titon Nur Ihsan [b,d], Tania Septi Anggraini [b,d,e], Agung Budi Harto [a,b], Albertus Deliar [a,f]

[a]Geospatial Information Science and Technology Research Group, Faculty of Earth Science and Technology, Bandung Institute of Technology, Bandung, Indonesia, 40132; virtriana@itb.ac.id (R.V.); albert@itb.ac.id (A.D.); agungbh@itb.ac.id (A.B.H.); akhmad.riqqi@itb.ac.id (A.R.); anjar@itb.ac.id (A.D.S.);*
[b]Center for Remote Sensing, Bandung Institute of Technology, Bandung, Indonesia, 40132; taniasepti@upi.edu *(T.S.A);kalinggatitonnurihsan@gmail.com (K.T.N.I.);*
[c]Geodesy and Geomatic Engineering, Faculty of Earth Sciences and Technology, Bandung, Indonesia, 40132.
[d]Doctor Program in Program Study of Geodesy and Geomatic Engineering, Faculty of Earth Sciences and Technology, Bandung, Indonesia, 40132.
[e]Geographic Information Science, Universitas Pendidikan Indonesia, Bandung 40111, Indonesia.
[f]Center for Spatial Data Infrastructure, Bandung Institute of Technology, Bandung, Indonesia, 40132.

KEYWORDS: hazard, flood, Pairwise Comparison, Geomorphic Flood Index (GFI)

ABSTRACT:

In 2022, there are 1,524 flood events out of a total of 3,531 disasters occurring in Indonesia. East Kalimantan Province ranked 20th among the 35 provinces in Indonesia with 28 flood occurrences in 2022, resulting in two fatalities. This highlights the urgent need for addressing flood hazard to prevent future casualties. There are some methods that can be used to determine the flood hazard in a region. In this research aims to identify flood-prone areas in East Kalimantan Province and evaluate the effectiveness of different mapping methods. The methodology that compares are the Pairwise Comparison method and Geomorphic Flood Index (GFI). The study's results provide flood-prone area maps of East Kalimantan Province using both methods, recommend the more efficient method for flood-prone area identification, and offer mitigation strategies based on the findings. This research is intended to serve as a reference for selecting the best method for identifying flood-prone areas and for informing policy decisions to mitigate flood impacts in East Kalimantan Province.

1. INTRODUCTION

Indonesia prone to flooding if environmental preservation is not properly maintained. Throughout 2022, the National Disaster Management Agency (BNPB, 2024) recorded 1,524 flood events out of a total of 3,531 disasters that occurred in Indonesia. East Kalimantan Province ranked 20th out of 35 provinces in Indonesia in terms of flood frequency, with 28 flood events in 2022. The floods in East Kalimantan in 2022 resulted in significant losses, including 2 fatalities, 3 injuries, 3 damaged homes, and 89,177 submerged houses.

Flooding in East Kalimantan Province is caused by several factors, including land cover changes (Virtriana et al., 2023) that associated with the development of office and residential areas in green zones (Warsilan, 2019). This land cover change cause of increasing the population (Ihsan et al., 2022a) in the area and urbanisation (Sakti et al., 2024). Moreover, this development was not accompanied by the construction of adequate drainage systems, causing water runoff to overwhelm river capacities and result in flooding.

Flood issues can be addressed through planning studies and detailed projects in flood-prone areas by identifying these areas (Faris and Syafira, 2019). Determining flood-prone areas is crucial for decision-makers in planning and managing flood-prone regions. This can be achieved through mapping. Flood vulnerability maps are tools used to assess flood vulnerability, helping to understand the level of risk. This study focuses on identifying flood-prone areas.

The flood vulnerability map in this research was created using Geomorphic Flood Index (GFI). The Geomorphic Flood Index (GFI) is a method used to estimate flood-prone areas on a large watershed scale (Lesmanawati and Fardani, 2022). The GFI method considers topographic factors represented by digital elevation model (DEM) data. This method combines ArcGIS version 10.1 and Quantum GIS version 2.0 to obtain flood elevation data using a geomorphological approach. The GFI method has also been widely used in similar studies, such as mapping flood-prone areas in the Kemuning Watershed in Sampang and mapping flood-prone areas in Pamanukan District, Subang Regency. Although East Kalimantan Province is categorized as a flood-prone area (BNPB, 2024), research on flood disasters in the region is still very limited, which motivated the author to conduct this study in the area.

2. LITERATURE REVIEW

Floods, according to the definition from the Multilingual Technical Dictionary on Irrigation and Drainage issued by the International Commission on Irrigation and Drainage, can be described as river flow rates that are relatively higher than usual, inundation occurring in lowland areas, as well as the rise, addition, and overflow of water that does not normally occur on land (Puturuhu, 2015). Floods can be categorized into two types of events: floods that occur in areas where flooding is uncommon, and floods resulting from water overflow from rivers when the flood discharge exceeds the river's capacity. Flood events themselves do not necessarily pose a problem unless they disrupt human activities within the flooded areas. In other words, a flood event does not become an issue or a natural hazard unless it causes harm or disruption to humans and the surrounding environment.

In general, indicators that contribute to flooding include relatively high rainfall intensity, particularly in upstream areas; low-lying areas; overflowing water in drainage channels due to

https://doi.org/10.5194/isprs-archives-XLVIII-M-5-2024-177-2025 |

elevated water levels in the main river (backwater effect); inadequate drainage systems, especially when irrigation channels have been repurposed as drainage channels (causing the channel's water level to be higher than the surrounding land); tidal surges coinciding with flood discharges in rivers; narrowing of river cross-sections; and changes in land use in the upstream watershed that tend to accelerate surface runoff (Kodoatie & Sugiyanto, 2002).

Floods can be caused by various factors, which are generally classified into two categories: natural factors and human factors. Natural factors include heavy rainfall, topographical conditions, inadequate soil absorption, river overflow, and natural events such as tidal surges or backwater effects. Human factors involve activities such as deforestation, improper land use, urbanization without proper drainage planning, and the alteration of natural water flow systems, all of which exacerbate the risk of flooding. The natural factors discussed in this study include surface elevation, slope gradient, land and distance to the river. According to Nuryanti et al. (2018), land slope influences the quantity and speed of surface runoff, surface drainage, land use, and erosion. The gentler the land slope, the slower the surface runoff is assumed to be, increasing the likelihood of inundation or flooding. Conversely, the steeper the land slope, the faster the surface runoff flows, causing rainwater to be quickly channelled away without inundating the area, thus reducing flood risk. This study uses a classification system to evaluate topographical slope conditions.

Elevation refers to the vertical distance or perpendicular distance from a specific reference plane to a point along its vertical line. In geodesy and geomatics, elevation is divided into two types: ellipsoidal height and orthometric height. In this study, surface elevation is determined using DEM (Digital Elevation Model) data from SRTM (Shuttle Radar Topography Mission), which is then classified. The elevation data from DEM SRTM is referenced to the WGS84 ellipsoid. The higher the elevation of an area, the lower the flood vulnerability compared to lower-lying regions.

A river buffer zone is an area with a specific width delineated around a river at a certain distance. River buffers are created based on logical reasoning and knowledge about the relationship between rivers and flood events. The assumption is that the closer an area is to a river, the higher its likelihood of experiencing flooding. Therefore, areas closer to the river are assigned higher values in the assessment.

3. DATA AND METHOD

3.1 Area Study

East Kalimantan has been designated as Indonesia's new capital city (IKN) based on Indonesia Law No. 3 of 2022 concerning the State Capital, which was enacted by the President of Indonesia in 2022. IKN is one of the provinces on the island of Kalimantan (also known as Borneo). The establishment of IKN has led to rapid development in East Kalimantan, causing significant land-use changes. As a result, this study was conducted in IKN as a form of flood disaster mitigation to address the potential risks associated with this development.

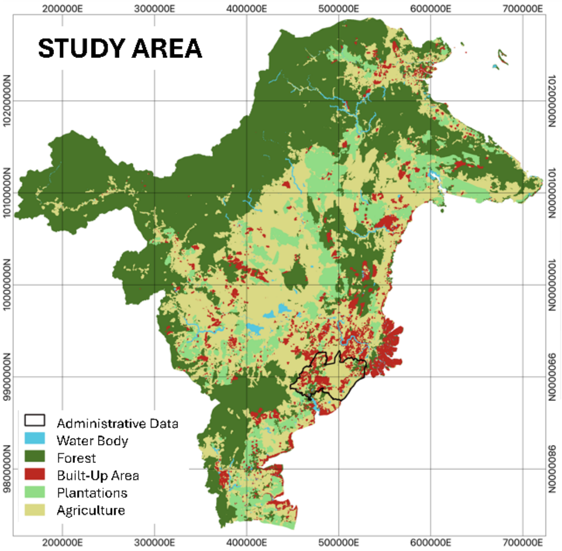

Figure 1. Study area (Sources: (KLHK, 2022))

East Kalimantan Province has indeed experienced land cover changes over the past eighteen years. From 2000 to 2009, these changes can be observed through the increasing areas marked in red, indicating land conversion to industrial or built-up areas. This shift may have been driven by population growth, which led to increased demand for land for housing. Additionally, in the northern part of East Kalimantan, land cover changed from forests to plantations. This transition was driven by both industries and local communities clearing land for palm oil plantations as a source of livelihood.

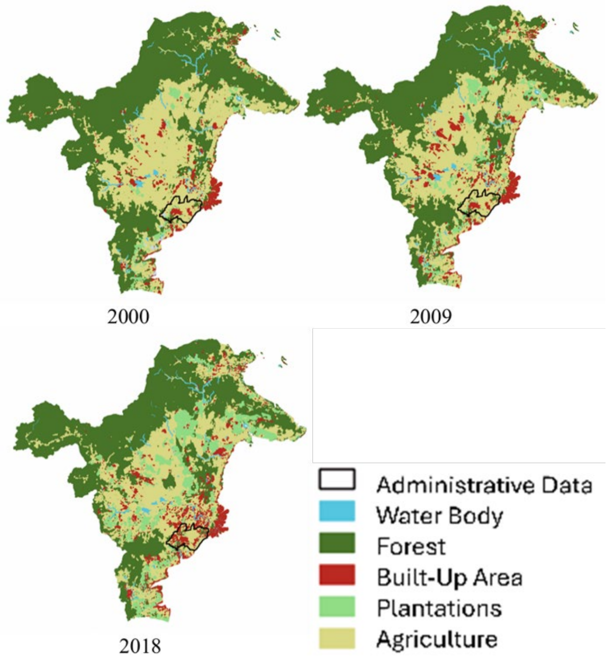
2000
2009
2018

Figure 2. Land use and land cover condition at study area in 2000, 2009, and 2018 (Sources: (KLHK, 2022))

From 2009 to 2018, land cover changes occurred in central East Kalimantan, with areas marked in red transitioning to light green, signifying land conversion from industrial or built-up areas to plantations. Meanwhile, red-marked areas became more widespread in the southern and western regions of East Kalimantan.

In the area designated as the future National Capital (IKN), minimal land cover changes were observed between 2000 and 2009. However, from 2009 to 2018, the IKN area experienced significant land cover changes to industrial or built-up areas, even though the IKN had not yet been officially established in 2018.

3.2 Data

In this study, five types of data were generally used, including elevation, land cover, rainfall, and river data for the pairwise comparison method, while elevation and river data were used for the GFI method. The specifications of the data used in this research can be found in Table 1.

Table 1. Data Specification

Dataset/ unit	**Product**	**Data Format**	**Time of Data**	**Resolution**	**Temporal Resolution**	**References**
Land Cover	KLHK	Raster	2000 - 2018	1: 250,000	Annualy	(KLHK, 2022)
Digital Elevation Model (DEM)	SRTM	Raster		30 m		(Jarvis et al., 2016)
River	BIG	Vector		1:25,000		(BIG, 2022)
Flood History	BNPB	Statictic	2014 - 2020			(BNPB, 2022)

Illustrations of the data used to build the flood model based on the GFI method in the form of slope, elevation, and distance from the river are shown in Figure 3, Figure 4, and Figure 5, respectively.

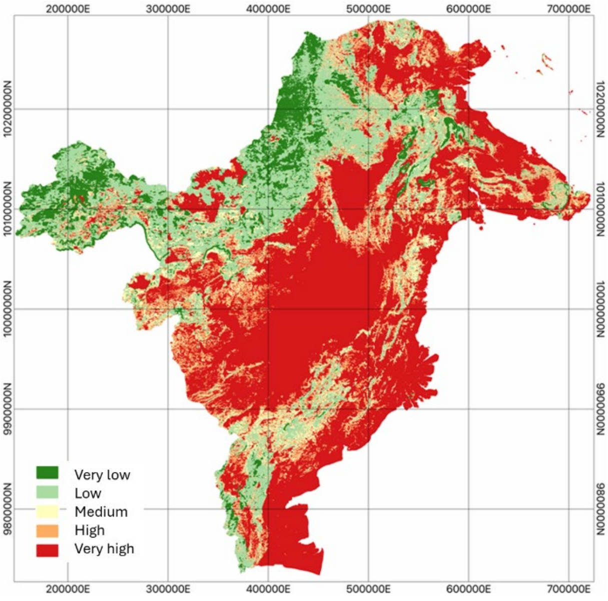

Figure 3. Slope to flood vulnerability

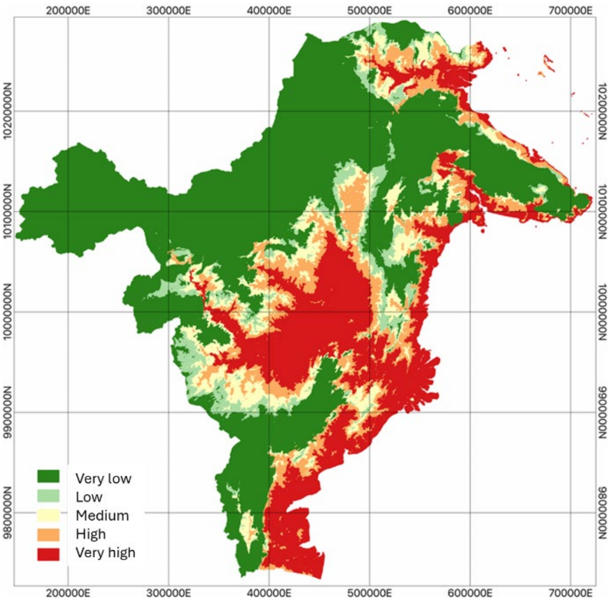

Figure 4. Elevation to flood vulnerability

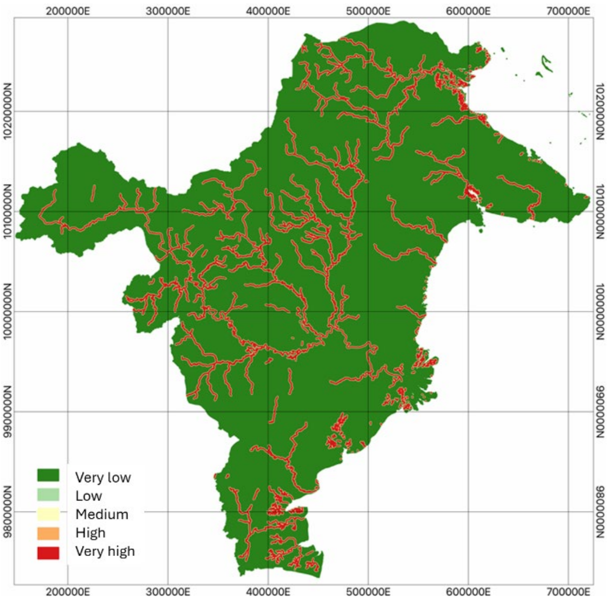

Figure 5. Distance from river to flood vulnerability

3.3 Method

In general, this study determines the flood-prone using GFI method. The overall methodology for each processing approach can be seen in Figure 6.

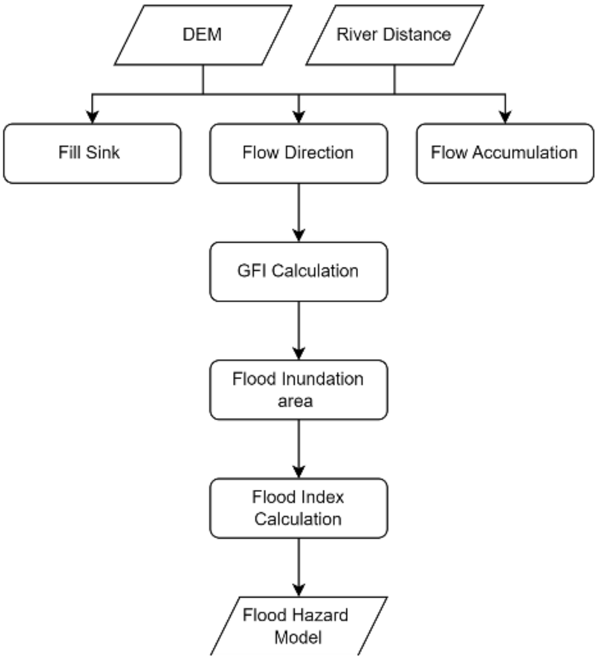

Figure 6. General Methodology GFI

The GFI method is used to determine threshold values. These threshold values are obtained by conducting tests using several pre-existing flood hydraulic models, ensuring the results are as accurate as possible. The GFI value is derived by comparing each point in the river basin between water depth (hr) and the elevation difference (H) between the tested point and the nearest point to the river network. Water depth (hr) is calculated as a function of the contributing area (Ar) within the nearest area hydrologically connected to the tested point. Therefore, by estimating hr from the water depth at the closest element of the river/drainage network, the nearest river/drainage is considered the source of the hazard.

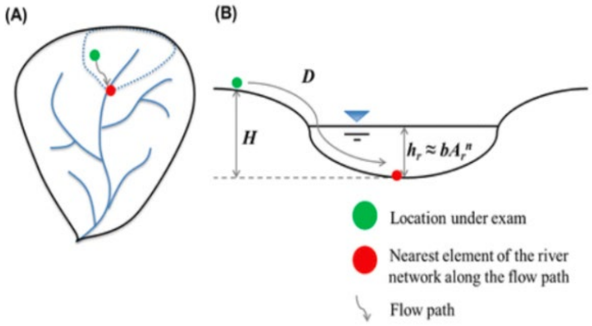

Figure 7. The Geomorphic Flood Index (GFI) process, as cited by Samela et al. (2017)

The potential inundation area can be determined using the method developed by Samela et al. (2017), known as the Geomorphic Flood Index (GFI). This method can be applied through an additional analysis tool (plugin) available in QGIS software version 2.0. GFI is a method used to estimate flood inundation areas on a large watershed scale, providing an effective and rapid procedure for regions with limited hydrological data.

GFI compares the index of each point's water depth (hr) in meters with the elevation difference (H) in meters. The variable hr is calculated as a function of the contributing area (Ar) in square meters at the nearest point of the river/drainage network hydrologically connected to the tested point. Therefore, by considering the estimated water level at the nearest element of the river/drainage network, the nearest river/drainage is regarded as the hazard source. Inundation values can be calculated using equation below. With GFI is Geographic Flood Index, hr is Elevation of the nearest element of the river network along the flow, and H is Floodwater height from the river surface.

$$GFI = \ln\left(\frac{hr}{H}\right)$$

4. RESULT AND DISCUSSION

4.1 Flood Prone Area Using GFI

The flood-prone area map above was generated using the Geomorphic Flood Index (GFI) method, with input data consisting of river flow and DEM data from East Kalimantan Province, as shown in Figure 8. From this map, it can be identified that flood-prone areas in East Kalimantan Province are located in the regencies of Penajam Paser Utara, Kutai Kartanegara, the city of Samarinda, and Berau. The areas marked in red indicate flood-prone zones where the predicted flood height may exceed 1.875 meters. Therefore, these red-marked areas fall into the very high-risk category for flood vulnerability.

The results indicate that 10.3% of the total area of East Kalimantan Province is classified as very high-risk. In the event of a flood, the water height in these areas could reach up to 1.875 meters. This flood height poses a significant danger to the local population, threatening lives and potentially causing extensive damage to residential buildings, public infrastructure, and the loss of valuable property.

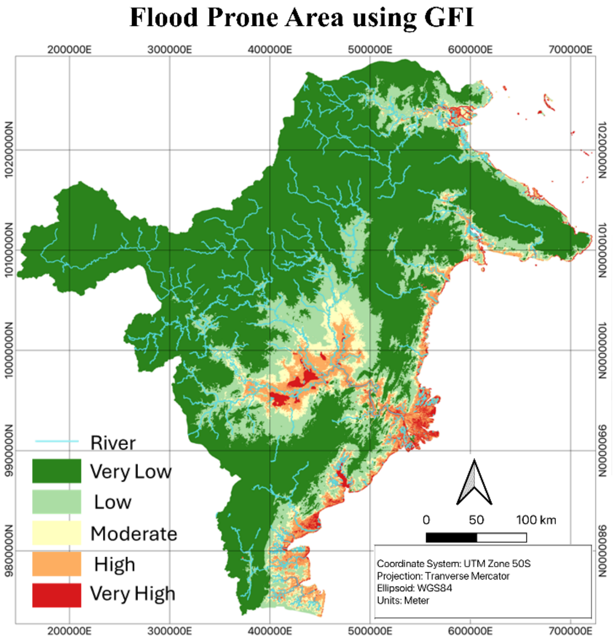

Figure 8. Flood Prone Area using GFI

4.2 Comparison GFI – Flood History

Historical flood data for East Kalimantan Province was sourced from the National Disaster Management Agency (BNPB) covering a six-year period from 2014 to 2020. This historical flood data serves as a comparison for flood-prone area maps generated using the Geomorphic Flood Index (GFI) method. The map considered more accurate is the one whose flood-prone area classifications align closely or match the historical flood map of East Kalimantan Province.

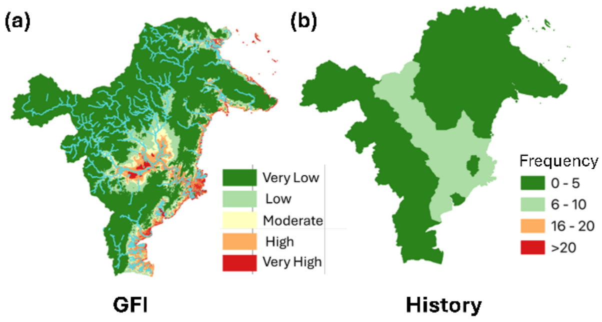

Figure 9. Comparison GFI – Flood History

Areas shaded in light green indicate that they experienced flood events between five and ten times within a single year, marking them as flood-prone areas. However, the flood event data from BNPB is reported at the city/regency level, which means that in this historical map, flood-prone areas encompass entire cities or regencies. In reality, only specific parts of these cities or regencies fall into the high flood-prone category. This limitation also applies to areas shaded in light and dark green, which might be classified as safe or not flood-prone.

The highly vulnerable area is in the southeast part of East Kalimantan Province. GFI method, which only considers the physical topography, shows the vulnerable area of flood hazard is near to the river. The areas predicted to have high flood vulnerability using the GFI method are Penajam Paser Utara Regency, Kutai Kartanegara Regency, Samarinda City, and Berau Regency.

4.3 Limitation and Future Possible Study

This study has several limitations that can be addressed in future research. First, the DEM resolution used in this study is a limitation. To obtain more accurate flood-prone area results using the GFI method, higher-resolution DEM data than the SRTM DEM is required. To increase the spatial resolution of DSM, machine learning method can be used (Ihsan et al., 2024, 2022b). Second, East Kalimantan only has three BMKG rainfall stations, and interpolating rainfall data from these stations yields coarse results, even though the pixel size has been reduced. To achieve more accurate flood-prone area determination, better-quality rainfall data is needed to produce a denser and more precise rainfall map. This research also can be good information to the conservation information for future (Virtriana et al., 2024).

4.4 Flood Disaster Mitigation Recommendations

Creating flood-prone area maps is one of the efforts in mitigating flood disasters. These maps allow the prediction of areas vulnerable to flooding, enabling the government, community, and other relevant parties to develop well-prepared plans to reduce the risks and losses caused by flooding. Additionally, mitigation efforts can also include developing flood disaster risk maps, flood disaster capacity maps, and flood risk maps that encompass the calculation of potential flood losses.

A suitable flood disaster mitigation effort for East Kalimantan Province is controlling land cover changes, particularly in forested areas. Given the high rainfall levels in East Kalimantan, the reduction of water catchment areas increases the likelihood of flooding and amplifies the resulting losses. Forest areas serve as the primary water catchment zones. However, over the past eight years, forest areas have been continuously declining due to infrastructure development and the conversion of forest land into plantations. Therefore, the government should enforce stricter policies on land cover changes, particularly in forest areas.

The second effort involves building adequate drainage infrastructure so that, during heavy rains, water can be directed to nearby rivers or reservoirs. Proper drainage infrastructure can prevent waterlogging.

5. CONCLUSION

The flood-prone areas identified by the AHP method include Paser Regency, Penajam Paser Utara Regency, Berau Regency, Samarinda City, Kutai Barat Regency, Kutai Timur Regency, and Kutai Kartanegara Regency. The flood-prone areas identified by the GFI method include Paser Regency, Penajam Paser Utara Regency, Kutai Barat Regency, Kutai Kartanegara Regency, Kutai Timur Regency, and Berau Regency. When comparing the flood-prone area maps generated by GFI method attend to have several same patterns with historical flood map of East Kalimantan Province.

ACKNOWLEDGEMENTS

This research was funded by LPPM-ITB under the Program Riset ITB 2024; 1583/IT1.C01/SK-TA.00/2024 grant scheme attributed to the Geospatial Information Science and Technology Research Group (KK-STIG).

REFERENCES

BIG, 2022. InaGeoportal [WWW Document]. URL https://tanahair.indonesia.go.id/portal-web (accessed 5.25.22).

BNPB, 2022. Statistik Bencana Menurut Jenis.

BNPB, 2024. Data Bencana [WWW Document]. URL https://gis.bnpb.go.id/databencana/tabel/pencarian.php (accessed 5.21.24).

Faris, F.M., Syafira, O.N., 2019. Pemetaan Wilayah Rawan Banjir Menggunakan Metode Spatial Multi-Criteria Evaluation (SMCE) di Sub DAS Minraleng, Kabupaten Maros, in: Seminar Nasional Penginderaan Jauh Ke-6.

Ihsan, K.T.N., Anantri, N.M.K., Syamsu, A.A., Mustika, F.C., 2022a. PREDICTION of POPULATION DISTRIBUTION in 2030 USING the INTEGRATION of the CA-ANN LAND COVER CHANGE METHOD with NUMERIC EXTRAPOLATION in KARAWANG-BEKASI, INDONESIA, in: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives. https://doi.org/10.5194/isprs-Archives-XLVI-M-2-2022-111-2022

Ihsan, K.T.N., Sakti, A.D., Higuchi, A., Takenaka, H., Wikantika, K., 2024. City-Level solar Photovoltaic potential using integrated digital surface models and HIMAWARI geostationary satellite in Jakarta and Bandung Cities, Indonesia. Energy Build 114552.

Ihsan, K.T.N., Sakti, A.D., Safitri, S., Wikantika, K., 2022b. Development of Low-Cost 3D Building Model Using National Digital Elevation Model in Urban Area of Bandung City, Indonesia, in: ECS Transactions. https://doi.org/10.1149/10701.16973ecst

Jarvis, A., H.I., Reuter, A., Nelson, A., Guevara, E., 2016. Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database. CGIAR CSI Consortium for Spatial Information.

KLHK, 2022. Basis Data Geospasial [WWW Document]. URL https://sigap.menlhk.go.id/sigap-v3/basis-data/index (accessed 1.15.23).

Kodoatie, R.J. dan Sugiyanto, 2002. Banjir, Beberapa Penyebab dan Metode Pengendaliannya dalam Perspektif Lingkungan, Pustaka Pelajar, Yogyakarta.

Lesmanawati, F., Fardani, I., 2022. Studi Identifikasi Tingkat Risiko Bencana Banjir di Kecamatan Pamanukan Kabupaten Subang. Jurnal Riset Perencanaan Wilayah Dan Kota 41–52.

Meteorology, C. and G.A., 2022. Data Online-Pusat Database BMKG [WWW Document]. URL https://dataonline.bmkg.go.id/home (accessed 12.3.22).

Nuryanti, N., Tanesib, J. L., & Warsito, A. (2018). Pemetaan Daerah Rawan Banjir Dengan Penginderaan Jauh Dan Sistem Informasi Geografis di Kecamatan Kupang Timur Kabupaten Kupang Provinsi Nusa Tenggara Timur. Jurnal Fisika: Fisika Sains dan Aplikasinya, 3(1), 73–79. https://doi.org/10.35508/fisa.v3i1.604.

Puturuhu, F. (2015). Mitigasi Bencana dan Penginderaan Jauh.Graha Ilmu Yogyakarta, Yogyakarta.

Sakti, A.D., Deliar, A., Hafidzah, D.R., Chintia, A.V., Anggraini, T.S., Ihsan, K.T.N., Virtriana, R., Suwardhi, D., Harto, A.B., Nurmaulia, S.L., 2024. Machine learning based urban sprawl assessment using integrated multi-hazard and environmental-economic impact. Sci Rep 14, 13385.

Samela C, Troy T J, and Manfreda S 2017. Geomorphic Classifiers for Flood-Prone Areas Delineation for Data-Scarce Environments Adv. Water Resour. 102 13- 28.

Virtriana, R., Anggraini, T.S., Ihsan, K.T.N., Alifah, M.N., Retnowati, D.A., Rohayani, P., Harto, A.B., Riqqi, A., 2024. Developing a spatial-based predictive model for conservation area management prioritization using ecosystem service and site suitability index in Java Island. International Journal of Applied Earth Observation and Geoinformation 126. https://doi.org/10.1016/j.jag.2023.103606

Virtriana, R., Deanova, M.A., Safitri, S., Anggraini, T.S., Ihsan, K.T.N., Deliar, A., Riqqi, A., 2023. Identification of land cover change and spatial distribution based on topographic variations in Java Island. Acta Ecologica Sinica. https://doi.org/10.1016/j.chnaes.2023.08.002

Warsilan, W., 2019. Dampak Perubahan Guna Lahan Terhadap Kemampuan Resapan Air (Kasus: Kota Samarinda). Jurnal Pembangunan Wilayah dan Kota 15, 70–82.