Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.14.1.101

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Flood Hazard Mitigation at Tarusan Watershed, South Pesisir District, West Sumatera Province

Iswandi Umar[a,b], Triyatno[a]

a Department of Geography, Faculty of Social Science, Universitas Negeri Padang, Padang, 25132, Indonesia
b Research Center Population and Environmental, Universitas Negeri Padang, Padang, 25132, Indonesia

Article History
Received 11 May 2023
Revised 21 June 2023
Accepted 13 August 2023

Keywords
flood, hazard, zone

ABSTRACT

Floods are the most common natural disasters in Indonesia and have enormous potential. This study aims to determine the flood hazard zone and regional arrangement in the Tarusan Watershed, South Pesisir Regency. To determine the flood hazard zone using the GIS approach. The indicators used to determine flood hazard are slope, rainfall, soil type, landform, geology, and land use. Determine the direction of regional arrangement with an Interpretative Structural Modeling (ISM) approach. The results showed that the high flood hazard zone in the Tarusan watershed is about 22% of the total area, the medium index is around 58%, and the low flood hazard index is 20%. The high-hazard zone of flood disasters in the study area is caused by high rainfall and topographic conditions of the Tarusan Watershed. The main priority in the management of flood-hazard areas in the Tarusan Watershed is to find economic alternatives to reduce forest destruction. Increasing the economic value of the community can lead to reduced community activities in carrying out land conversion, especially in forest areas.

Introduction

Flooding is a natural phenomenon that occurs when high rainfall intensity exceeds the capacity of a watershed system [1]. Floods are influenced by three main factors: human, meteorological, and watershed characteristics [2–3]. Furthermore, Kodoatie et al. classified the factors causing flooding into natural factors and human factors. Natural factors that encourage flooding include high rainfall intensity, relatively flat topography, narrowing of river bodies, and siltation due to sedimentation. In addition, human activities can also cause flooding, such as deforestation, settlements along rivers, and dumping garbage into rivers. According to data from the Indonesian National Disaster Management Agency, from 1,815 to 2022, around 34.7% of the total national disasters were floods. Based on causative factors, 45% are caused by human behavior [4].

Flood disasters are disasters that often occur in the tropics, especially in the Tarusan Watershed. The flood disaster in the Tarusan Watershed disrupted transportation routes connecting the cities of Padang and Painan as the capital of the southern coastal regency and Bengkulu Province. The flood event also has an impact on the disruption of the flow of goods and people crossing this area, disruption of transportation flows in this area due to flooding can reach about nine hours. impacts the people who live in the Tarusan Watershed, such as disruptions in community economic and agricultural operations. Flood events in the Tarusan Watershed typically cause agricultural land to be flooded, resulting in crop failure for the community.

Rosyidie stated that increasing human needs encourage changes in land use and behavior towards the environment which are factors in floods [5]. The Tarusan Watershed is currently an area with high flood intensity. The increasing intensity of flooding in the Tarusan Watershed is influenced by several factors. Based on Landsat's imagery, there was a reduction in forest area by 1.7% per year from the period 2000–2018. The

Corresponding Author: Iswandi Umar iswandi_u@yahoo.com Department of Geography, Faculty of Social Science, Universitas Negeri Padang, Padang, Indonesia.

reduction of these forest friends has an impact on river sedimentation. In addition, anthropogenic factors include settlements on riverbanks, mining of mineral C, and forest encroachment. This study aims to determine the mitigation and flood hazard areas in the Tarusan Watershed, Pesisir Selatan Regency. This study is important for flood mitigation efforts in the study area.

Method

Study Area

This study was conducted in the Tarusan Watershed, Pesisir Selatan Regency, West Sumatra Province. This study was conducted over five months, from January to May 2022. Figure 1 shows the research locations. The Tarusan Watershed has an area of 300.27 km^2 and is one of the ten largest river basins in West Sumatra Province. The Tarusan Watershed was emptied into the Indian Ocean. Based on the Shuttle Radar Topography Mission (SRTM) 1 Arc Second imagery in the form of a Digital Elevation Model (DEM), approximately 30% of the study area has flat topography. The average rainfall intensity for this friend was high, at more than 3,000 mm/year.

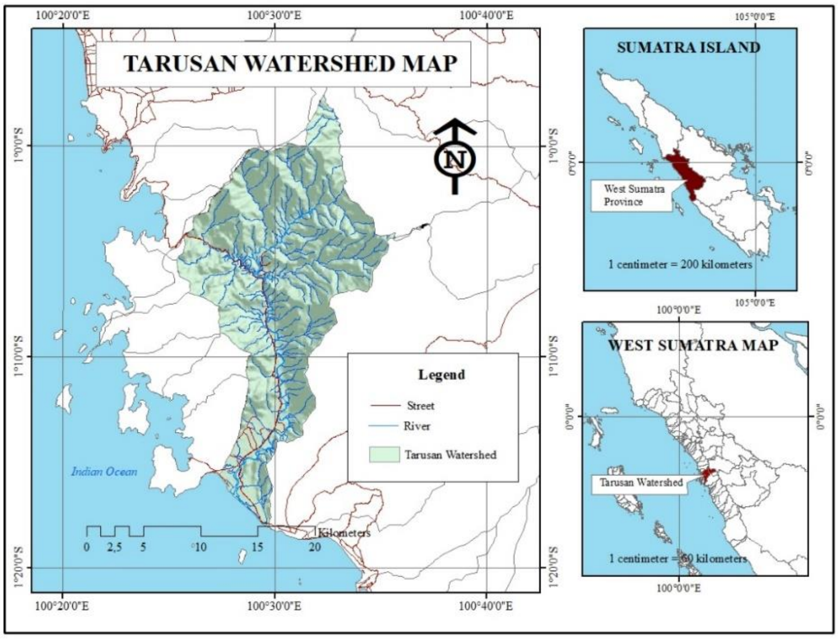

Figure 1. Study location Tarusan Watershed.

Data Analysis

Six indicators were used to determine the flood hazard zone: rainfall, slope, land shape, land use, soil type, and geological formation. The rainfall data used was sourced from *Badan Meteorologi, Klimatologi and Geofisika (BMKG) Sicincin* for the period 1975–2022 which was isolated from isohyet lines. The slope is generated from the DEM from the SRTM 1 arc-second image. Furthermore, landform data were generated from the interpretation of geological formations, vegetation, and DEM. Information about land cover can also be obtained by interpreting the imagery extracted from Landsat Oli 8 imagery. Soil types in the study area were sourced from the Bogor Soil Research Center in 1990. Geological formations used data from the Bandung Geological Agency. The data requirements of this study are presented in Table 1.

Table 1. Research material.

No	Data	Specification	Sources
1.	Rain falls	Period 1975–2022	*BMKG Sicincin*
2.	Slope	SRTM Art 1 Imagery	USGS
3.	Landform	Analysis data	
4.	Land use	Landsat OLI 8, year 2020	USGS
5.	Type of Soil	Map scale 1: 250.000 year 1990	Bogor Soil Research Center
6.	Formation of geology	Map scale 1: 250.000 year 2007	Bandung Geological Agency

To determine the flood hazard zone in the Tarusan Watershed, a scoring method was used using the analysis technique of map overlay on a geographic information system (GIS). Each indicator is detailed or divided into sub-indicators. The score value was generated by multiplying the weight of the indicator with the value of the sub-indicator (Table 2) [6]. To determine the class of flood hazards, Equation 1 was used. Table 2 shows the indicators used to determine the flood hazard zone. The highest total score resulting from the multiplication of weight and dignity was 325, whereas the lowest total score was 65. In this study, the result of the flood hazard zone was classified into three hazard classes: high, medium, and low. Using Equation 1, an interval class value of 86 was generated. Table 3 presents the flood hazard class intervals for the Tarusan Watershed.

Table 2. Indicator for assessment flood hazard.

Indicator / weight	Sub indicator	Value	Score
Rain fall (mm/years) / 15	> 4,500	5	75
	4,000 – 4,500	4	60
	3,500 – 4,000	3	45
	3,000 – 3,500	2	30
	< 3,000	1	15
Slope (%) / 15	Flat (0 – 8%)	5	75
	Tilted (9 – 16%)	4	60
	little steep (17 – 26%)	3	45
	Steep (27 – 40%)	2	30
	Very steep (> 40%)	1	15
Landform / 10	Marin	5	50
	Fluvial	4	40
	Denudational	1	10
	Structural	1	10
	Vulcanic	1	10
Land use / 10	Bare land	5	50
	Settlement	4	40
	Farming area	4	40
	Mixed garden	3	30
	Shrub	3	30
	Plantation	2	20
	Forest	1	10
Soil / 10	Ultisols	5	50
	Entisols	4	40
	Histosols	3	30
	Oxisols	2	20
	Inceptisols	1	10
Geology / 5	Alluvium (Qal)	5	25
	Latih formation (Tml)	3	15
	Jura Sediment (Jr)	3	15
	Granite (Tgr)	1	5
	Quaternary Mountain Rock (Qv)	1	5

Source: Umar et al. [6]

$$I = \frac{c-b}{k} \quad (1)$$

where: I = class interval; c = total highest score; b = total lowest score; k = the number of classes desired.

Table 3. Class interval flood hazard.

Hazard classification	Class interval	Index
Low	65 – 115	Low
Medium	116 – 237	Middle
High	238 – 325	High

Source: Umar et al. [6]

The arrangement of the Tarusan watershed area for flood hazards was carried out using the interpretative structural modeling (ISM) method. To explain and determine cause and effect relationships in very complex problems, the ISM method is very effective to use [7]. Furthermore, Umar et al. stated that flood hazard mitigation requires complex considerations and many stakeholders [8]. Complex problems can be solved by using the ISM method. Marimin divides the stages of the ISM method into several stages, namely: (1) determining elements and sub-elements; (2) expert assessment of the contextual relationship between sub-elements with the VAXO symbol; (3) determine the SSIM matrix; (4) determine the Reachability Matrix (RM); (5) transivity; (6) determining the vertical hierarchical structure; and (7) determining the Driver Power (DP) and dependence (D) relationship metrics. The structural self-interaction matrix (SSIM) is created by means of pairwise comparison with the VAXO symbol [9]. Where this symbol has meaning is:

V if Eij = 1 and Eji = 0; V = i th sub element is more important than j sub element and not vice versa.

A if Eij = 0 and Eji = 1; A = sub element to j is more important than sub element to i and not vice versa.

X if Eij = 1 and Eji = 1; X = the two sub-elements have the same role level value and are related to each other, and

O if Eij = 0 and Eji = 0; O = the two sub elements are not related

Furthermore, Eriyatno [7] and Marimin [9] classified elemental relationships into four categories (Figure 2):

The first quadrant is called autonomous and consists of sub-elements that have a driver power value (DP) ≤ 0.5 X and a dependence value (D) ≤ 0.5 X, where X is the number of sub-elements on each element. Sub-elements in the first quadrant can be interpreted as unrelated or have little relationship with the system.

The second quadrant is called dependent, consisting of sub-elements that have a driver power value (DP) ≤ 0.5 X and a dependence value (D) ≥ 0.5 X. Sub-elements in the second quadrant are sub-elements that depend on elements in the third quadrant.

Quadrant III: Linkage consists of sub-elements that have a driver power (DP) value ≥ 0.5 X and a value of dependence (D) ≥ 0.5 X, where X is the number of sub-elements in each element. The sub-elements included in quadrant III need to be studied carefully because every action on one sub-element affects the other sub-elements in quadrants II and IV.

Quadrant IV: Driver (Independent) consists of sub-elements that have a value of driver power (DP) ≥ 0.5 X and a value of dependence (D) ≤ 0.5 X, where X is the number of sub-elements in each element.

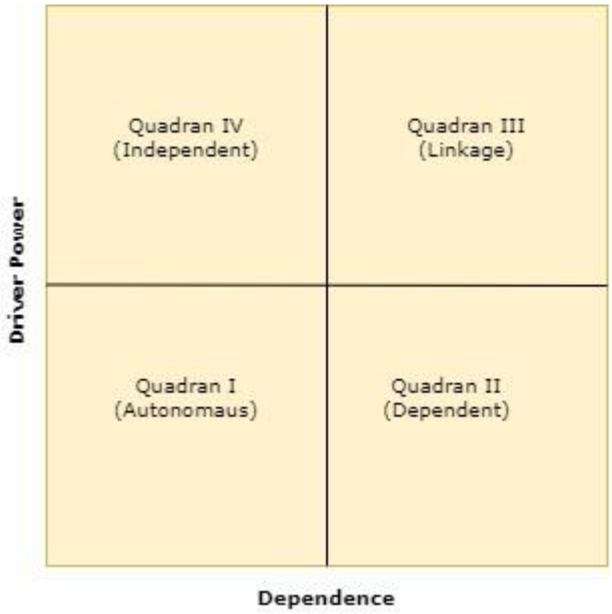

Figure 2. Matrix of driver power and dependence of ISM.

Result and Discussion

The Tarusan Watershed has a relatively diverse topography. In general (63%) has a steep-to-steep slope, and only about 15 percent of the area of the Tarusan Watershed has relatively flat slopes. Slope conditions dominated by steep categories encouraged high erosion. The soil types in the study area are mostly Oxisol soils (around 45 percent), and according to Usman, these soil types have physical properties that are easy to erode [10]. Namdar and Pelko add that the oxisol soil of this type of soil has low absorption of rainwater, which encourages an increase in runoff [11]. In addition, Sutrisno et al. stated that an increase in global temperature encourages an increase in rainfall in a certain region and time. Increased rainfall is a driving force for flood disasters [12]. Umar et al. and Hoch et al. stated that the area that is very dangerous when the intensity of rainfall is high is the area of the fluvial formation process (alluvial fans, natural embankments, river meanders). This area is the formation of fluvial process fields [8,13].

Based on land use in 2019, the Tarusan watershed, with approximately 62% of the water catchment area, is forest, while the rest is used for cultivated land. The annual forest conversion rate was 0.7% between 2000–2019 periods. According to Akhter and Hewa [14], Chen and Tfwala [15], forest conversion to other uses will have a direct impact on the flood zone. According to Umar et al., it is necessary to have cross-sectoral synchronization and consistency in the law enforcement of land use budgeting [16]. The results of the flood hazard zone analysis in the Tarusan Watershed show that there is 22% high hazard, approximately 58% medium hazard, and 20% low hazard. The details are shown in Figure 3 and Table 4.

Based on the interpretation of Land Sat Oli 8 imagery, land use in 2020 in the study area is still dominated by forested areas. In addition, the results of the analysis of the relationship between the flood hazard zone and land use in the Tarusan Watershed show that residential areas and agricultural food crops are located in high-risk zones. Wagenaar et al. and Ferrans argued that settlements and agriculture that grow and develop in flood hazard areas need an arrangement to minimize the risk of disasters in the future [17,18]. Furthermore, Nkwunonwo et al. and Umar et al. found that an increase in population has a significant effect on land requirements, such that land that is not suitable and disaster hazards will be an option for use in the future [19,16].

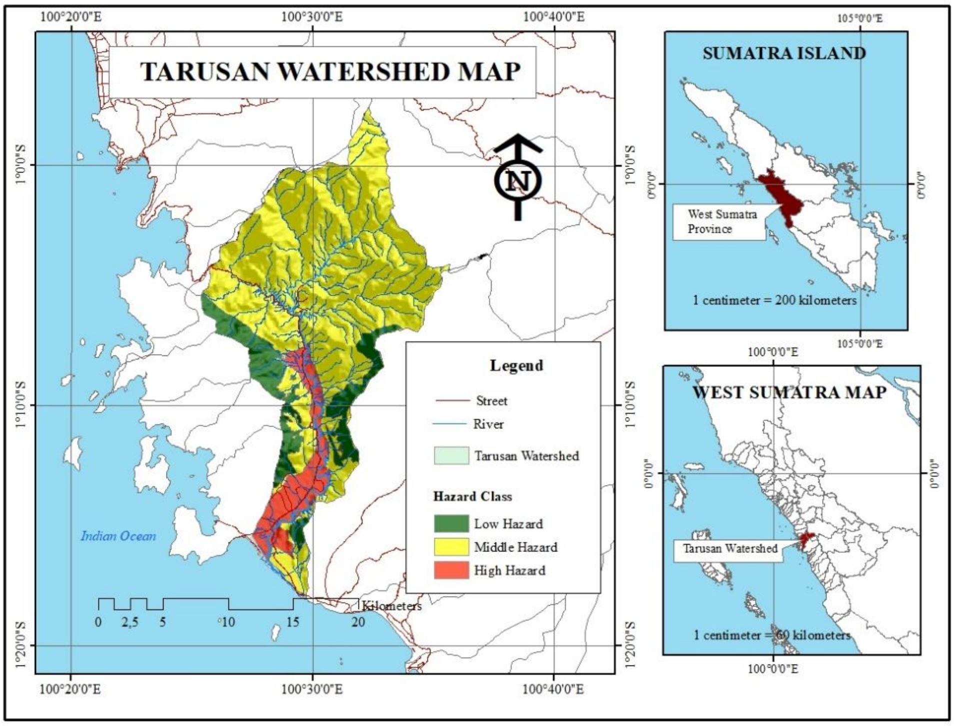

Figure 3. The flood hazard zone in the Tarusan Watershed.

Table 4. The flood hazard area in the Tarusan Watershed.

No	Hazard classification	Area (Ha)	Percentage
1.	Low	6,629.96	22.08
2.	Medium	17,295.55	58.6
3.	High	6,101.49	20.32
Total (Ha)		30,027	100

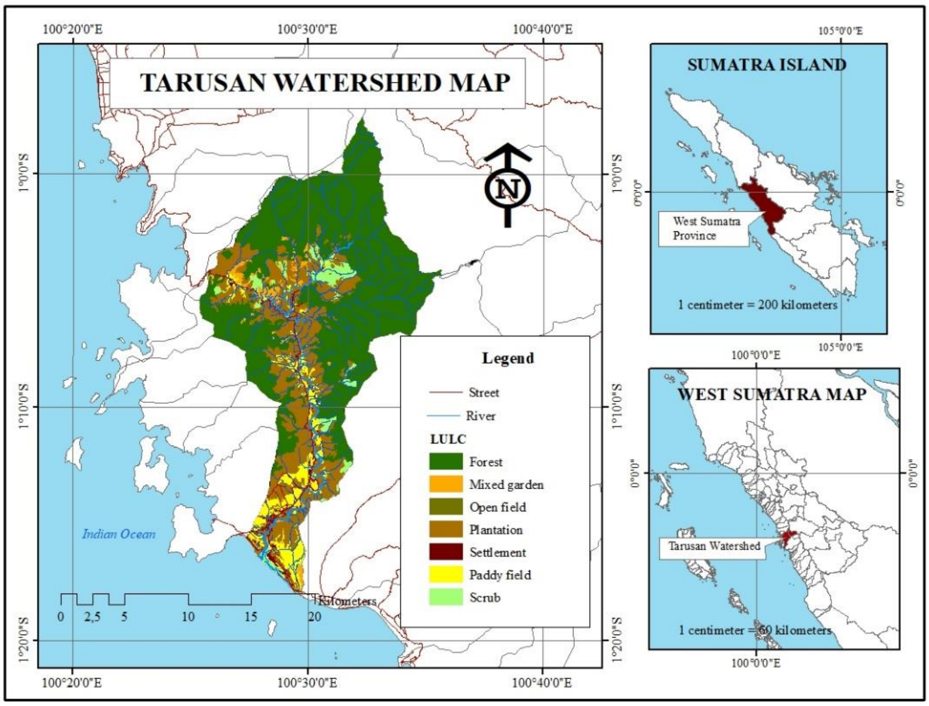

Figure 4. Map of land use in the Tarusan Watershed.

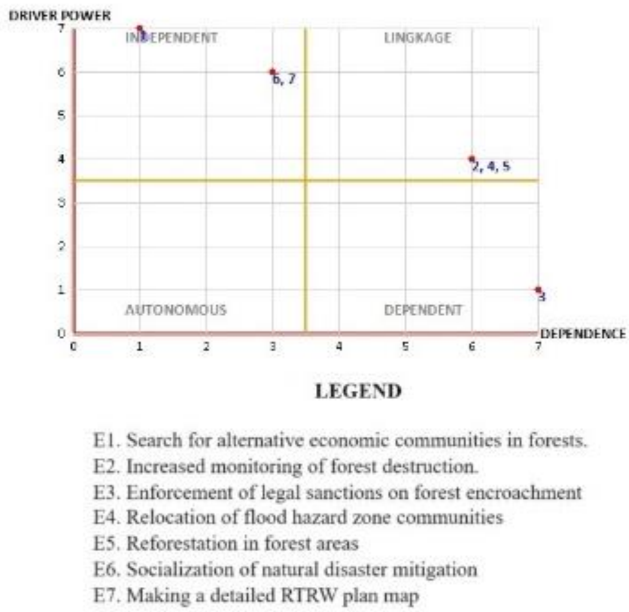

Figure 5. Tarusan Watershed structuring policy.

To determine the contextual relationship between elements, is determined based on expert opinions. Experts involved in determining the contextual relationship of elements come from related stakeholders, namely: (1) Center for Population and Environmental Research Universitas Negeri Padang, (2) Regional disaster management agency Agam Regency, (3) Non-Governmental Organizations (NGOs), (4) Public Works Office of Agam Regency, and (5) Community leaders. Twenty experts were involved in determining the policy directions, and 20 people were involved. Some considerations in determining experts in research are as follows: (1) having experience in the field under study, (2) having a reputation or competence with the field being studied, and (3) having high credibility in the field under study.

The results of the Focus Group Discussion (FGD) with stakeholders revealed seven sub-elements of the direction for the arrangement of the Tarusan watershed area: E1. Search for alternative economic communities in forests, E2. Increased monitoring of forest destruction, E3. Enforcement of legal sanctions on forest encroachment, E4. Relocation of flood hazard zone communities, E5. Reforestation in forest areas, E6. Socialization of natural disaster mitigation, E7. Making a detailed RTRW plan map.

Based on the results of the ISM analysis, three sub-elements have high driver power and low dependence (Figure 5): E1 (search for alternative economies for communities around forests), E6 (socialization of natural disaster mitigation), and E7 (making detailed RTRW plan maps). As a policy direction for the Tarusan Watershed arrangement, there are four levels (Figure 6), and the priority of this direction is to search for alternative economies for the community around the forest. Chechina et al. [20] stated that there is a significant relationship between the level of community income and forest destruction. The higher the level of community income, the less forest damage there will be. Delabre et al. [21], Wicander and Coad [22] added that efforts to reduce forest damage require an alternative economic search by the community for economic improvement.

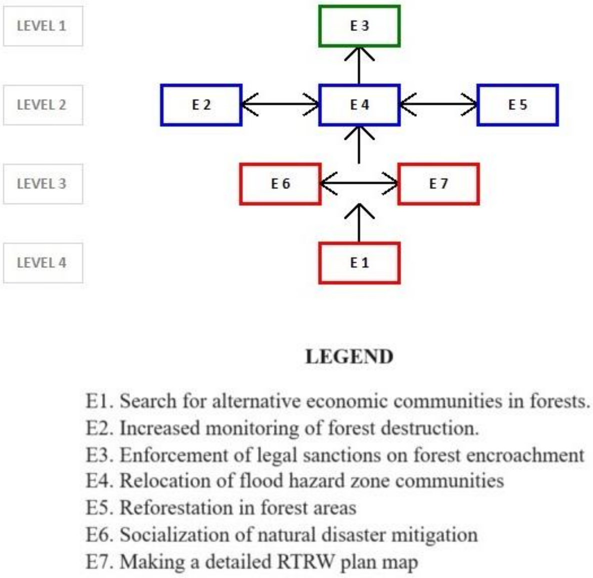

Figure 6. The hierarchical structure of the Tarusan Watershed structuring policy.

Conclusion

Based on the research results, it can be concluded that there are flood-prone zones with an estimated 22% high flood zones. As a policy direction for mitigating flood disasters in the Tarusan Watershed, it is necessary to look for economic alternatives for communities around the forest so as not to damage the forest. Apart from that, public awareness through disaster mitigation outreach needs to be increased. Enhancing the community's economy is necessary to lessen the reliance on land and mitigate the flood calamity in the Tarusan Watershed. Reducing human involvement in land cover can improve the Tarusan Watershed's high water-holding capacity, which can lessen the watershed's tendency to flood.

Acknowledgements

Acknowledgments are only made to appropriate parties: sponsors, donors of materials, and research facilities. If the scientific work is sourced from a research grant from a sponsor, also write the contract number. All names listed have been confirmed and are willing to be listed and published.

References

1. Suripin. *Sistem Drainase Yang Berkelanjutan,* 1^{st} Edition; CV Andi: Yogyakarta, ID, 2014; ISBN 979-731-137-6.

2. Asdak, C. *Hidrologi dan Pengelolaan Daerah Aliran Sungai*; Gadjah Mada University Press: Yogyakarta, Indoensia, 1995; ISBN 978-602-386-845-2.
3. Bashir, B. Morphometric Parameters and Geospatial Analysis for Flash Flood Susceptibility Assessment: A Case Study of Jeddah City along the Red Sea Coast, Saudi Arabia. *Water Journal* **2023**, *15*, 870–882.
4. Kodoatie; Robert, J.; Suharyanto; Sangkawati, S.; Edhisono, S. *Pengelolaan Sumber Daya Air dalam Otonomi Daerah*; CV Andi: Yogyakarta, ID, 2002; ISBN 9795338757.
5. Rosyidie, A. Banjir: fakta dan dampaknya, serta pengaruh dari perubahan guna lahan. *Journal of Regional and City Planning* **2013**, *24,* 241–249.
6. Umar, I.; Widiatmaka; Pramudya, B.; Barus, B. Prioritas Pengembangan Kawasan Permukiman Pada Wilayah Bahaya Banjir Di Kota Padang, Provinsi Sumatera Barat. *Majalah Ilmiah Globe* **2017**, *19*, 83–94.
7. Eriyatno. *Ilmu Sistem: Meningkatkan Mutu dan Efektifitas Manajemen*; IPB Press: Bogor, ID, 2003; ISBN 979-545-048-4.
8. Umar, I.; Dewata, I.; Barlian, E.; Hermon, D.; Suasti, Y. Priority Selection of Residential Development Areas with Flood Hazard in Limapuluh Kota District, West Sumatra. *International Journal of GEOMATE* **2018**, *15*, 152–158.
9. Marimin. *Teknik dan Aplikasi: Pengambilan Keputusan Kriteria Majemuk*; PT. Grasindo: Jakarta, ID, 2005; ISBN 979-732-449-4.
10. Usman, S. Surface soil factors and soil characteristics in geo-physical milieu of kebbi state nigeria. *Eurasian Journal of Soil Science* **2016***, 5*, 209–220.
11. Namdar, A.; Pelko, M.K. Numerical analysis of soil bearing capacity by changing soil characteristics. *Frattura Ed Integritá Strutturale* **2009***,* 10, 38–42.
12. Sutrisno, A.J.; Kaswanto; Arifin, H.S. Analisis Prediksi dan Hubungan antar Debit Air dan Curah Hujan pada Sungai Ciliwung di Kota Bogor. *Journal of Natural Resources and Environmental Management* **2019**, *10*, 25–33.
13. Hoch, J.M.; Eilander, D.; Ikeuchi, H.; Baart, F.; Winsemius, H.C. Evaluating the impact of model complexity on flood wave propagation and inundation extent with a hydrologic–hydrodynamic model coupling framework. *Natural Hazards and Earth System Sciences* **2019***, 19,* 1723–1735.
14. Akhter, M. S.; Hewa, G.A. The use of PCSWMM to assess the impacts of land use changes on hydrological responses and performance of WSUD in managing the impacts at the myponga catchment, south Australia. *Water Journal* **2016***, 8*, 511–522.
15. Chen, C.; Tfwala, S.S. Impact of climate change and land subsidence on inundation risk. *Water* **2018***, 10,* 157–165.
16. Umar, I.; Dewata, I.; Barlian, E. Konsistensi Rencana Tata Ruang Permukiman Dan Arahan Kebijakan Pembangunan di Kabupaten Tanah Datar, Provinsi Sumatera Barat. *Journal of Natural Resources and Environmental Management* **2019**, *9*, 277–286.
17. Wagenaar, D.J. ; de Bruijn, K.M.; Bouwer, L.M. ; de Moel, H. Uncertainty in flood damage estimates and its potential effect on investment decisions. *Natural Hazards and Earth System Sciences* **2016***, 16,* 1–14.
18. Ferrans, P.; Reyes-Silva, J.D.; Krebs, P.; Temprano, J. Flood Management with SUDS: A Simulation–Optimization Framework. *Water Journal* **2023**, *15*, 426–444
19. Nkwunonwo, U.C.; Whitworth, M.; Baily, B. Review article: A review and critical analysis of the efforts towards urban flood risk management in the lagos region of nigeria. *Natural Hazards and Earth System Sciences* **2016***, 16*, 349–369.
20. Chechina, M.; Neveux, Y.; Parkins, J.; Hamann, A. Balancing conservation and livelihoods: A study of forest-dependent communities in the philippines. *Conservation and Society* **2018***, 16*, 420–430.
21. Delabre, I.; Boyd, E.; Brockhaus, M.; Carton, W.; Krause, T.; Newell, P.; Zelli, F. Unearthing the myths of global sustainable forest governance. *Global Sustainability* **2020***, 3*, 1–10.
22. Wicander, S.; Coad, L. Can the provision of alternative livelihoods reduce the impact of wild meat hunting in West and Central Africa. *Conservation and Society* **2018***, 16*, 441–458.