Application of Spatial Model for Potential Flood Hazard Susceptibility at Trumon Area, South Aceh Regency of Indonesia

Ella Meilianda[1,2*], *Dedy* Alfian[2], *Fitri Z.* Nurnalisa[2] and *Maimun* Rizalihadi[1], *Ziana* Ziana[1]

[1]Civil Engineering Department, Engineering Faculty, Universitas Syiah Kuala, Jl. Abdur Rauf 11, Kopelma Darussalam, Banda Aceh, 23111, Indonesia

[2]Tsunami and Disaster Mitigation Research Center (TDMRC), Universitas Syiah Kuala, Jl. Hamzah Fansuri 8, Kopelma Darussalam, 23111, Indonesia

Abstract. Indonesia is currently embarking on a transition from a 'risk retention' to a 'risk transfer' strategy for managing the impact of disaster events. The risk transfer strategy, i.e., insurance policy and protection, requires high-level preliminary risk assessment, which requires detailed attention and analysis in producing hazard mapping. Improvement of methods requires, preferably, the non-deterministic index method in a GIS environment, to produce reasonably good quality hazard susceptibility mapping. Recently, a new spatial method has been developed to improve the parameterization of the spatial analysis method for watershed-scale flood hazard susceptibility mapping. Those parameters, which include the Topographic Wetness Index (TWI), Rainfall Intensity (R), Distance to rivers (D), Altitude (A), Land use (L), and Soil type (S), configure the proposed method called "TWIRDALS". The present study aims at testing the spatial model TWIRDALS watershed at the Trumon Area, South Aceh Regency, Sumatra Island, Indonesia. Historical flood events associated with the watershed have escalated over the last 25 years in the Trumon watershed. Several steps of geospatial analysis in this study use multi-temporal satellite imagery from 1995 to 2021 to identify area changes in land use rendering over the watershed. The satellite imagery interpretation reveals a remarkable land use change, particularly of the previously 2130 ha of peatland forest observed in 1996, to become a 10,000 ha palm oil plantation in 2021. This current situation has made the Trumon area the recipient of more frequent floods, i.e., from a five-year return period to an annual event.

1 Introduction

Flood events have been affecting millions of people around the world, leading to social and physical losses and jeopardizing the economic condition of a nation. Despite in general considered as low severity, floods have been recorded as the highest number of occurrences among the other type of hazards worldwide, thus, potentially leading to an expensive disaster. A developing and economic emergence country with significantly high population growth, expands the settlements and built infrastructure development to remote areas, triggering landuse changes; i.e., from the permeable vegetated land, to impermeable urbanized areas, which have increased the potential impact of the flood hazard. Furthermore, flood events may be accompanied by landslides or flash flood, an additional hazard with potentially catastrophic impact on settlements and human lives [1]. The weekly disaster update for the regional ASEAN, flood events have always persistently been the most frequent hazard among the other predominant hazards affecting the region, which includes floods, landslides, wind-related, and earthquake. Over the last 18 years, Indonesia has suffered losses of approximately $16.8 billion due to disaster events [2].

Rapid development and climate change are increasing Indonesia's exposure and vulnerability to disaster risk, particularly flood and seismic risk, and these trends have implications for the safety, liability and prosperity of communities across the country [3]. Flood events recorded to harm the existing infrastructure, agricultural land and citizens' lives. The urbanized rural areas put pressure on the capacity of a watershed or watershed to increasing flood events.

In a case of high frequency, low severity disasters such as fluvial and pluvial floods, sufficiently high quality of preliminary risk assessment remains a challenge, especially if rely on deterministic hydraulic modelling, when long-term hydrological data has been hardly available. Therefore, improvement of methods needed, in a GIS environment, to produce reasonably good quality of hazard susceptibility mapping.

Flood risk analysis incorporates flood hazard mapping, which makes it possible to estimate the spatial extent of flood characteristics like velocity, depth, and frequency effectively [4]. Flood hazard maps are important for flood control strategies because they effectively depict the geographic range and distribution

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* Corresponding author: ella_meilianda@usk.ac.id

of flood susceptibility, and are relevant in evaluating global flood risk [5,6]. The analysis of a typical flood hazard map needs to be able to reveal details about the geographic scope, depth, and frequency of flooding. Flood hazard maps specification and ranking of flood-prone regions rely on the end users' requirement. [7]

Flood susceptibility analysis is the initial step to identify the level of hazards and vulnerability, thus, risks of the investigated areas to the flood potential. Therefore, flood susceptibility mapping and assessment is an important element of flood prevention and mitigation strategies because it identifies the most vulnerable areas based on physical characteristics that determine the propensity for flooding [8]. Assessing flood hazard susceptibility takes into account multi-parameters that matters for possible overland flow within a watershed. Such a demanding task requires substantial data, which often unavailable for a limited-investigated area. In validating a flood risk modelling, the choice of the technique to be implemented depends mainly on the availability of data for validation [6]. Comparison with observed data requires first that the modelled quantity is measurable, and second that measurements of real data are actually available.

In 2012, the Indonesian National Disaster Management Authority (BNPB) has developed a national standard guideline to produce risk map, which is the index-based risk map resulting from the hazard, vulnerability and capacity indices [9]. In particular for calculating the hazard index, it adopts the geomorphic approaches using Digital Elevation Model (DEM) to predict inundation depth proposed by [10]. Afterwards, the Central Government of Indonesia has invested in providing infrastructure enabling the effort of flood risk assessment through a web-GIS portal for disaster risk assessment in Indonesia called "InaRISK" [11]. InaRISK was officially launched by BNPB in 2016. It summarizes the results of disaster risk assessment that provides risk mapping of disaster-prone areas, which consists of 12 types of disasters, including flood. It provides information of multi-disaster affected population, potential physical and economic loss, and environmental damage. It is also claimed to serve as a tool for monitoring the decline of disaster risk index as it is also linked to the realization of disaster risk reduction program implementation.

Indonesia is currently embarking from a 'risk retention' to a 'risk transfer' strategy for managing the impact of disaster events. The risk transfer strategy, i.e. insurance policy and protection, requires high-level preliminary risk assessment, which requires detailed attention and analysis in producing hazard mapping. In a case of high frequency, low severity disasters such as fluvial and pluvial floods, sufficiently high quality of preliminary risk assessment remains a challenge, especially if rely on deterministic hydraulic modeling, with modeling solution might be simplified and limited to a certain aspect of the flooding, in addition to hardly available long-term hydrological records. Therefore, alternative methods are needed.

The method applied by BNPB to identify the potential flood hazard by using the DEM-based method firstly introduced by [10]. It predicts inundation depth expressed in the geomorphic flood index (GFI), which is useful for quantifying flood induced damages. Recently, a geomorphic-based indexed method to delineate flood hotspots has been developed using Topographic Wetness Index (TWI) method [12,13], which was initially introduced by [14]. The TWI is an index that has a purely topographic interpretation and quite straightforward to calculate in a GIS environment, makes it ideal for very large areal extents [13,15]. The present study aims to develop a watershed-scale hazard susceptibility mapping in GIS environment. incorporating customized hydro-spatial parameterizations. include topographic wetness index (TWI), rainfall, distance to river, altitude, landuse and soil types.

2 Study location

Trumon watershed has an area of 53,653 hectares, located in the Trumon Sub District which is part of South Aceh Districts in Aceh Province of Indonesia (Fig. 1). The main river in the Trumon watershed is Krueng Trumon which has a length of ± 21 km with a slope of 0.0003 and an average discharge of 13.42 m3/second [39]. Based on the division of the rain zone from BMKG (Meteorological and Geophysical Agency) data, it shows that the Trumon area, South Aceh Regency is included in the Non ZOM (Out of Season) zone with periods of high to extreme rainfall intensity occurring twice a year, the period March-May and October-December. Forests is land cover fields are the majority of this area, followed by plantation which is palm oil dominant. The morphology of the study area is generally divided into plains, hills and mountains. The average height is 151 m, the maximum height is 1093 m and the minimum height is 0.00 meters as coastline. Based on land system, shallow peat swamp dominant which cover 33.91% of total areas or 18,196.92 Ha. Average slope is 0.0052 % in plain areas.

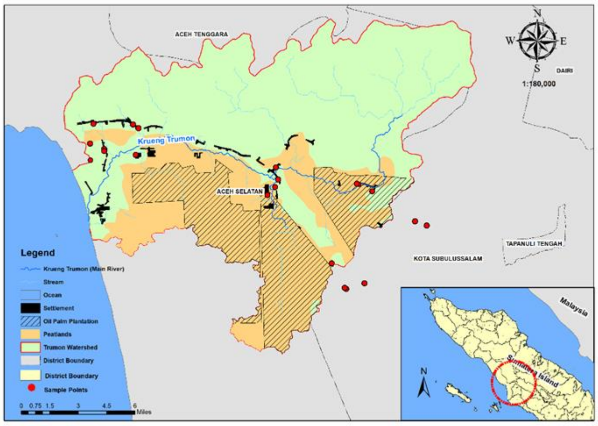

Fig. 1. Trumon watershed in South Aceh District, Aceh Province, Indonesia. Palm oil plantation is mostly located in flood plain, where the soil type is commonly peat.

Trumon watershed, located in the Trumon District of South Aceh Regency, is one of the many watersheds under critical conditions in Indonesia's Aceh Province. Historical flood events associated with the watershed have escalated over the last 25 years at the Trumon watershed. This is in line with the increasing oil palm plantation openings within this 53,262 Ha peatland dominant watershed area. From previous studies, massive and continuous land use changes over the peatland areas may lead to land subsidence. Being mostly situated at the downstream of a watershed, the reclaimed peatland may serve as a recipient of flood events during the rainy season.

3 Data and Methods

The data used in this study include data from previous studies, field surveys and spatial data such as DEM, land system maps and oil palm plantation areas (Table 1).

Table 1. Data type used in the present study

	Data	Data Type	Data Source
1	Land Subsidence Information (cm/ per year)	Secondary	Output Research [16]
2	Topografi Data (DEM)	Secondary	BIG (Geospatial Information Agency) Indonesia, https://earthexplorer.usgs.gov/
3	Data Landsystem, Landcover and Palm Oil Plantation	Secondary	BIG (Geospatial Information Agency) Indonesia
4	Flood history and profile data	Primer	Field Survey

3.1 Potential Flood Hazard Index (PFHI)

The present study proposes a methodology to develop a customized hydro-spatial parameterization in a GIS environment to define flood hazard areas in a watershed scale.

3.2 Criteria parameterization

Figure 2 schematized the methodology which overall aim is to identify hotspots related to flood hazard potential, thus, to flood risk. Herein, the customized hydro-spatial criteria parameterization in this study consider six parameters the topographic wetness index (TWI), rainfall (R), distance to river (D), altitude (A), landuse (L) and soil types (S), which herein are abbreviated as "TWIRDALS".

The selection of the parameters is theoretically based on their relevance contributing to the overland flow process and hydrological theories which culminating into the source of excessive temporal water inundation the area within a watershed boundary, which in this case called 'flood inundation'(Haan et al, 1994). In addition, the methodology also considers about the availability of data of those parameters in Indonesia, which are provided in the form of thematic mappings in GIS environment.

3.3 Criteria weights

Once the six criteria have been processed in a GIS environment and visualized in independent thematic maps of the studied area, the next step is to determine the values of the grid-point of every parameter which are classified in normalized weighting factors. The classes of the TWI and altitude are products of the digital elevation model (DEM). Moreover, the altitude and rainfall intensity were defined using the grading method of natural breaks which has been used in similar studies [17], [18]. Apart from determining the wetted terrain from excess rainfall identified by TWI, the distance from river is another important factor to calculate the time it takes for the surface runoff drained into the closest river network from the adjacent land. In this study, the distance from rivers was calculated using the Euclidean distance tool in ArcGIS software based on the vector layer of a river network, which method was used in [8].

The land use parameter is associated with the vegetation cover that controls both the amount of precipitation and the time it takes to reach the soil surface contributing to the surface runoff [18], [19]. Land use influences infiltration rate, the interrelationship between surface and groundwater as well as debris flow [17]. In the tropical watershed, weathering process and soil erosion immensely contribute to the land cover and the soil properties.

3.4 Analytical Hierarchy Process (AHP)

The weight of each parameter is defined by using the Analytical Hierarchy Process (AHP) [20]. AHP is a structured technique used for analyzing complex problems, where a large number of interrelated objectives or criteria are involved. The weights of these criteria are defined after they are ranked according to their relative importance. Thus, once all criteria are sorted in a hierarchical manner, a pairwise-comparison matrix for each criterion is created to enable a significance comparison. The relative significance between the criteria is evaluated from 1 to 9 indicating less important to much more important criteria, respectively. Weighting by AHP is widely used in many applications [8], [20][21] and is recommended to be used for regional studies [1], [17]. The proposed methodology is adopting similar approach named as FIGUSED which mostly applied in the Mediterranean territories (e.g. [1], [17]). The present study is using 6 x 6 matrix, where diagonal elements are equal to 1. The criteria of the TWIRDALS method are sorted in a hierarchical manner, for the studied watershed. The values of each row characterize the importance between two parameters. A pairwise comparison of the criteria significance resulted to the principal eigenvalues of

Table 2. Moreover, a normalized value of the parameters of table 3, their mean and eventually the corresponding weight *w* of each factor is displayed in Table 3.

Table 2. Matrix of flood hazard parameters using AHP

Parameter	TWI	R	D	A	L	S
TWI	1	2	2	3	5	7
R	0.50	1	2	3	5	7
D	0.50	0.50	1	2	4	7
A	0.33	0.33	0.50	1	4	6
L	0.20	0.20	0.25	0.25	1	3
S	0.14	0.14	0.14	0.17	0.33	1

Table 3. Normalized flood hazard parameters

	TWI	R	D	A	L	S	Mean	w_i
TWI	8	0.48	0.34	0.32	0.26	0.23	0.33	3.32
R	0.19	0.24	0.34	0.32	0.26	0.23	0.26	2.61
D	0.19	0.12	0.17	0.21	0.21	0.23	0.19	1.87
A	0.12	0.08	0.08	0.11	0.21	0.19	0.13	1.33
L	0.07	0.05	0.04	0.03	0.05	0.10	0.06	0.57
S	0.05	0.03	0.02	0.02	0.02	0.03	0.03	0.30

The acquired values are processed in order to calculate the relative significance of each criterion of the weights, the PFHI can be calculated using Eq. (1).

$$PFHI = \sum_{i=1}^{n} p_i . w_i = TWI.w_{TWI} + R.w_R + D.w_D + A.w_A + L.w_L + S.w_S \tag{1}$$

where:

p_i the score of the parameter in each point
w_i the weight of each parameter
n the number of the criteria

The weighting factors requires further examination on the consistency of the resulting parameters prioritization, using Eq. (2):

$$CR = \frac{CI}{RI} \tag{2}$$

where:

CR the consistency ratio
CI the consistency index
RI the random index (number of parameters)

The value of RI is determined based on the Random Index (RI) tabulated in Table 4.

Table 4. Value of Random Index

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The consistency index (CI) is calculated using Eq. (3):

$$CI = \frac{\lambda - n}{n - 1} \tag{3}$$

where:

n the number of factors
λ the average value of the consistency vector

The consistency ratio (CR) suggested in AHP must be <0.1. The consistency index (CI) herein was calculated for $\lambda = 6.35$, $n = 6$, and $RI = 1.24$, resulting in the consistency ratio $CR = 0.05692$, which is lower than the CR's threshold.

3.5 Producing parameter thematic maps

The data sources to produce the thematic maps consists of moderate resolution DEM, or LIDAR for better resolution and accuracy, vector maps, mostly of polygon types, and raster maps. All types of vector data were converted into the raster format with the cell size of 10 x 10 m. The sources of data to produce the thematic maps of multiple parameters are displayed in Table 5.

Table 5. Data sources used for processing thematic maps of flood hazard susceptibility factors

Thematic map	Data	Format	Source
TWI	River network map	Vector (shapefile)	DEMNAS Badan Informasi Geospasial (BIG)
	Slope map		
	Elevation map		
Rainfall Intensity	Daily max rainfall distribution map	Raster (tiff)	Giovanni BMKG
Distance from river	River buffer map	Raster (tiff)	DEMNAS Badan Informasi Geospasial (BIG
Altitude	DEM	Raster (tiff)	DEMNAS Badan Informasi Geospasial (BIG)
Land use	Land use polygon map	Vector (shapefile)	Forestry and Bio-Environment Bureau (DLHK Aceh Province)
Soil types	Soil types polygon map	Vector (shapefile)	Forestry and Bio-Environment Bureau (DLHK Aceh Province)

4 Results and Discussion

From the hierarchy analysis, we found the hierarchical sequence of parameterization sequences as Topographic Wetness Index (TWI), rainfall intensity (R), Distance from river (D), altitude (A), land use (L), and soil types (S), or abbreviated as "TWIRDALS" method.

4.1 TWIRDALS parameters

Each of TWIRDALS parameter was spatially and individually analysed using different techniques in GIS environment, and produced in individual thematic maps. The followings are the description of each parameters and the results from the spatial data processes and analysis for each parameter.

4.1.1 Topographic Wetness Index (TWI)

The present study modifies the method to analyze the rainfall excess over the watershed terrain using the TWI. In unmapped areas, TWI can be used as a first step to determine sampling and model development [22]. TWI allows for the delineation of patches within a watershed perimeter which potentially exposed to flood inundation. This can be achieved by identifying all the areas where a TWI exceeds a given threshold calibrated using precise delineation of inundation profile samples [12], [23]. Figure 2 depicted the result of spatial analysis to produce TWI thematic map of Trumon watershed using remote sensing data from satellite image Landsat in GIS-environment. . The TWI is an index that has a purely topographic interpretation and quite straightforward to calculate in a GIS environment, makes it ideal for very large areal extents [15].

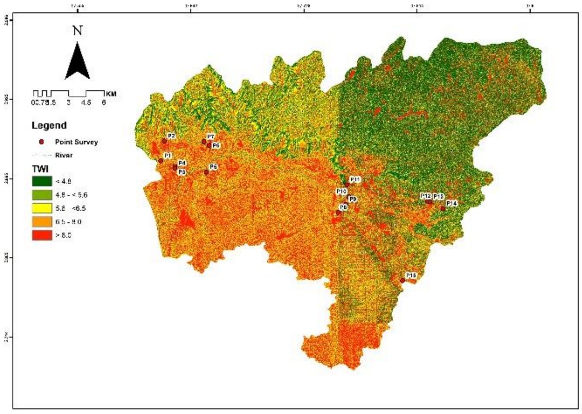

Fig. 2. The result of spatial analysis to produce TWI thematic map of Trumon watershed using remote sensing data from satellite image Landsat in GIS-environment.

4.1.2 Rainfall Intensity (R)

Rainfall is understood as a causal triggering factors for local or regional scale analysis [8]. Therefore, the average monthly rainfall intensity from several rain gauge stations nearby the investigated watershed is required. Nevertheless, station-based rainfall data in Indonesia is sparse. Alternatively, thanks to the advanced remote sensing technology, continuous rainfall data from the satellite can be accessible. The present study obtained the maximum daily rainfall data from the Geospatial Interactive Online Visualization and Analysis Infrastructure (Giovanni) of The Global Precipitation Measurement website run by NASA [24]. Figure 3 shows the thematic map for rainfall intensity using the GPM and TRMM missions.

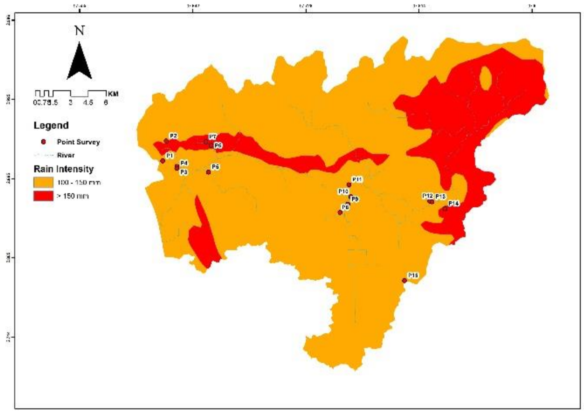

Fig. 3. The resulting thematic map of rainfall intensity distribution over the Trumon watershed.

4.1.3 Distance from River (D)

Distance from rivers is another important factor to calculate the time it takes for the surface runoff drained into the closest river network from the adjacent land. This parameter is in fact enforces the flow accumulation to the river, apart from determining the wetted terrain from excess rainfall identified by TWI. In this study, the distance from rivers was calculated using the Euclidean distance tool in ArcGIS software based on the vector layer of a river network, which method was used in [8].

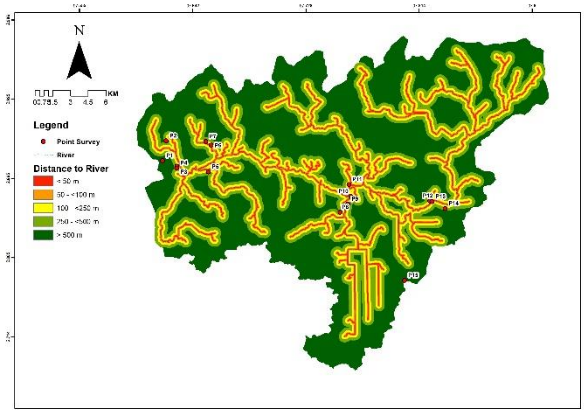

Fig. 4. The buffering zone of distance from river map derived from the river channel network in the Trumon watershed.

4.1.4 Altitude (A)

Altitude of the investigated watershed was derived from the corrected DEM, which data is made available for free by the Indonesian Geospatial Information Agency (BIG). The so-called DEM Nasional (DEMNAS) is generated from various sources of data, such as IFSAR (5 m resolution), TERRASAR-X (5 m resolution), and ALOS PALSAR (11.25 m resolution). Also, it incorporated the mass point resulting from the stereo-plotting operation. The overall spatial resolution of DEMNAS is 0.27-arcsecond, using vertical datum EGM2008 [25].

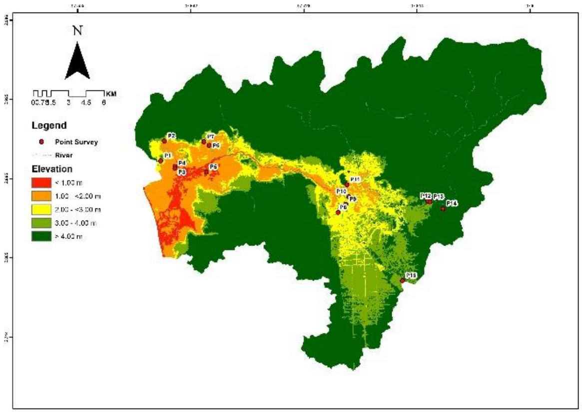

Fig. 5. The resulting thematic map of altitude of the entire Trumon watershed using multisource DEM.

4.1.5 Landuse (L)

Land use influences infiltration rate, the interrelationship between surface and groundwater as well as debris flow [1], [17]. The land use parameter is associated with the vegetation cover that controls both the amount of precipitation and the time it takes to reach the soil surface contributing to the surface runoff [19]. For many purposes in development programs in provincial level in Indonesia, the provincial level of landuse maps are frequently updated by the Provincial Environmental and Forestry Service (DLHK) Office.

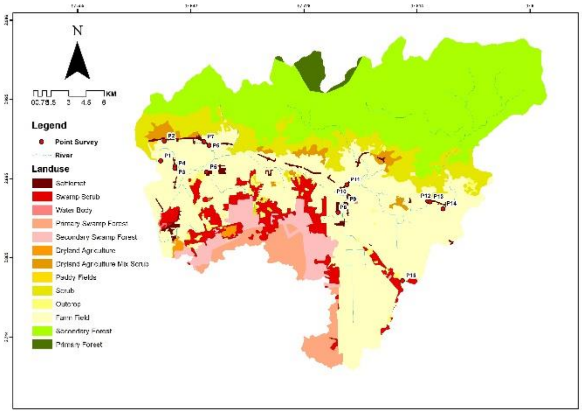

Fig. 6. The resulting thematic map of landuse to determine the rate of infiltration over the entire Trumon watershed.

4.1.6 Soil types (S)

In the tropical watershed, weathering process and soil erosion immensely contribute to the land cover and the soil properties. The hydrologic soil properties control rainfall excess over the watershed's morphological terrain by controlling the water infiltration, water holding capacity, and storage of water in soils [26], [27]. Therefore, in the present study, we consider more the importance of soil type than the geology factor, since the soils have different rate of permeability, thus, control the rate of surface runoff, infiltration, soil erodibility and flood retainment.

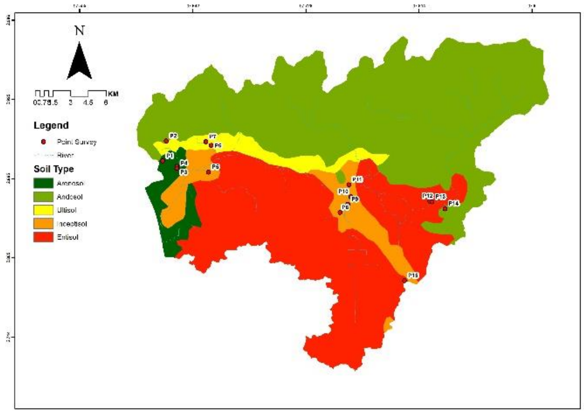

Fig. 7. The resulting thematic map of soil type to define the variability of percolation rate over the entire Trumon watershed.

Table 6. Classes of normalized weighting factors, the hierarchy and relative importance of criteria

Parameter	Class	Index score	Weight factor
TWI	>8.0	5	3.32
	6.5 – 8.0	4	
	5.6 – 6.5	3	
	4.8 – 5.6	2	
	<4.8	1	
Rainfall (mm)	>150	5	2.61
	100 – 150	4	
	50 – 100	3	
	10 – 50	2	
	<10	1	
Distance from rivers (m)	<50	5	1.87
	50 – 100	4	
	100 – 250	3	
	250 – 500	2	
	>500	1	
Altitude (m)	<1	5	1.33
	1-2	4	
	2-3	3	
	3-4	2	
	4-15.5	1	
Land use	Built environment	5	0.57
	Agricultural land	4	
	Grass land and bushes	3	
	Plantation	2	
	Forest	1	
Soil types	Entisol	5	0.30
	Inceptisol, Oxisol	4	
	Vertisol, Ultisol	3	
	Andosol, Molisol	2	
	Arenosol	1	

Each soil type bares different level of permeability equivalent to the classification of hydrologic soil types which more commonly used to analyse the rainfall excess by using the empirical curve numbers [8], [28], [29].

The overall important parameters are classified into a normalized weighting factors, the hierarchy and relative importance of criteria, which is shown in Table 6.

4.2 Validation and sensitivity analysis

Validation of the spatial analysis results in this study was using the flood inundation point locations from a field survey in Trumon area in 2022. The surveyed points indicate the locations where flood events were frequently inundating in the past decade. Figure 8 shows the distribution point locations from the survey overlaying the potential flood hazard map resulting from the TWIRDALS method. It is clearly shown that the surveyed point locations are distributed over the highly inundated watershed area, thus, validate the result of the spatial analysis using TWIRDALS method.

4.3 Potential flood hazard in Trumon watershed

The AHP analysis results in the level of importance of multiple parameters being used in this study. While similar like Kazakis et al. (2015) in using FIGUSED method to consider rainfall intensity is crucial in identifying flood prone areas, in this study the results from the AHP analysis demonstrate that hypothetically the most defining values for flood hazard is the TWI, where the wetness potential due to surface runoff is controlled by the topographic terrain. This is because the TWI is the domain of potential surface water accumulation caused by the rainfall intensity and duration.

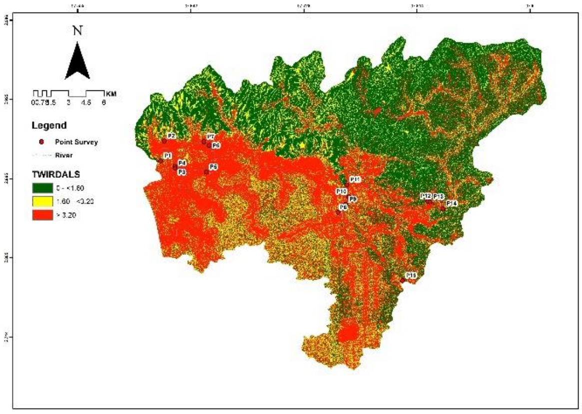

Fig. 8. The resulting thematic map of soil type to define the variability of percolation rate over the entire Trumon watershed.

Given that the approach depends only on the topographic value and slope, setting a threshold, therefore necessary. Despite this, all the other parameters in this study will be the factors that co-delineate the flood inundation boundaries. This includes separating the excess of rainfall on the surface that runs to the river network, i.e., by incorporating the distance to river map, from the flood inundation over the terrain away from the river channels by using TWI.

In addition, the hydrologic soil properties control rainfall excess over the watershed's morphological terrain by controlling the water infiltration, water holding capacity, and storage of water in soils [26], [27]. We consider landuse/landcover and soil type, in addition to the slope and altitude. Specifically, compared to the previous studies which were mostly located in Mediterranean and European continent [1], [8], [17]–[19] the importance of soil type considered to be more predominant than the geology factor. This is because in tropical countries like Indonesia, the weathering of rocks and other geological features are more prominent, thus, it is important to take into account the soil permeability. The soils have different rate of permeability, thus, control the rate of surface runoff, infiltration, soil erodibility and flood retainment. Overall, data sources used for processing the thematic maps of the flood hazard of the Trumon watershed is displayed in Table 1.

Figure 8 reveals the composition of areas susceptible to flood in the Trumon watershed. Out of a total of 21,070 hectare watershed area which has the highest risk to flood hazard, 59.17% is farm field, 11.69% is the secondary forest, 7.86% is swamp shrub, 5.96% secondary swamp shrub, 5.19% primary swamp forest, 4.16% shrub and the rest of 5.97% consists of various agriculture land, settlement and water body. The results show that

From the results of Pearson's correlation analysis between our field survey data vs modeled susceptibility index from the TWIRDALS method, we found that the correlations between the surveyed inundation heights and the flood susceptibility index is 0.53, whilst its correlation to the flood duration is 0.56. Both shows positive moderate correlations.

Using the proposed method "WITHDRALS", the results from the present study demonstrate the capability to determine the extent of potential flood inundations both sourced from the river outspill and the overland inundation. This improves the methodology to map the flood hazard susceptibility, particularly in the improperly managed floodplain which is typical in the less developed rural areas, or another extreme, at built environment with unregulated drainage system.

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References

[1] O. Patrikaki, N. Kazakis, I. Kougias, T. Patsialis, N. Theodossiou, and K. Voudouris, "Assessing flood hazard at river basin scale with an index-based approach: The case of mouriki, greece," *Geosci.*, vol. 8, no. 2, 2018, doi: 10.3390/geosciences8020050.

[2] C. for R. on the E. of D. CRED, "EM-DAT (The International Disaster DAtabase)," 2022. .

[3] R. I. Hapsari and M. Zenurianto, "View of Flood Disaster Management in Indonesia and the Key Solutions," *Am. J. Eng. Res.*, vol. 5, no. 3, pp. 140–151, 2016.

[4] A. Díez-Herrero and J. Garrote, “Flood Risk Analysis and Assessment, Applications and Uncertainties: A Bibliometric Review,” *Water*, vol. 12, no. 7, p. 2050, Jul. 2020, doi: 10.3390/w12072050.

[5] G. Di Baldassarre, A. Castellarin, A. Montanari, and A. Brath, “Probability-weighted hazard maps for comparing different flood risk management strategies: a case study,” *Nat. Hazards*, vol. 50, no. 3, pp. 479–496, Sep. 2009, doi: 10.1007/s11069-009-9355-6.

[6] R. B. Mudashiru, N. Sabtu, I. Abustan, and W. Balogun, “Flood hazard mapping methods: A review,” *J. Hydrol.*, vol. 603, p. 126846, Dec. 2021, doi: 10.1016/j.jhydrol.2021.126846.

[7] B. Merz, H. Kreibich, R. Schwarze, and A. Thieken, “Review article &quot;Assessment of economic flood damage&quot;,” *Nat. Hazards Earth Syst. Sci.*, vol. 10, no. 8, pp. 1697–1724, Aug. 2010, doi: 10.5194/nhess-10-1697-2010.

[8] M. Vojtek and J. Vojteková, “Flood Susceptibility Mapping on a National Scale in Slovakia Using the Analytical Hierarchy Process,” *Water*, vol. 11, no. 2, p. 364, Feb. 2019, doi: 10.3390/w11020364.

[9] M. R. Amri *et al.*, *RBI - Risiko Bencana Indonesia*. Jakarta: Direktorat Pengurangan Risiko Bencana BNPB, 2016.

[10] S. Manfreda and C. Samela, “A digital elevation model based method for a rapid estimation of flood inundation depth,” *J. Flood Risk Manag.*, vol. 12, no. Suppl. 1, 2009, doi: https://doi.org/10.1111/jfr3.12541.

[11] BNPB, “InaRISK.” 2016.

[12] S. H. Pourali, C. Arrowsmith, A. Matkan, and D. Mitchel, “Topography Wetness Index Application in Flood-Risk-Based Land Use Planning,” *Appl. Spat. Anal. Policy*, vol. 9, pp. 39–54, 2016, doi: https://doi.org/10.1007/s12061-014-9130-2.

[13] R. De Risi, F. Jalayer, F. De Paola, and S. Lindley, “Delineation of flooding risk hotspots based on digital elevation model , calculated and historical flooding extents : the case of Ouagadougou,” *Stoch. Environ. Res. Risk Assess.*, vol. 32, no. 6, pp. 1545–1559, 2018, doi: 10.1007/s00477-017-1450-8.

[14] M. J. Kirkby, “Hydrograph modelling strategies,” in *Progress in physical and human geography*, R. F. Peel and M. D. Chisholm, Eds. London: Heinemann, 1975, pp. 69–90.

[15] G. Kandilioti and C. Makropoulos, “Preliminary flood risk assessment: the case of Athens,” *Nat. Hazards*, vol. 61, no. 2, pp. 441–468, Mar. 2012, doi: 10.1007/s11069-011-9930-5.

[16] A. Aswandi, R. Sadono, H. Supriyo, and H. Hartono, “KEHILANGAN KARBON AKIBAT DRAINASE DAN DEGRADASI LAHAN GAMBUT TROPIKA DI TRUMON DAN SINGKIL ACEH (Carbon Loss from Drainaged and Degradation of Tropical Peatland in Trumon and Singkil, Aceh),” *J. Mns. dan Lingkung.*, vol. 23, no. 3, p. 334, Feb. 2017, doi: 10.22146/jml.18807.

[17] N. Kazakis, I. Kougias, and T. Patsialis, “Assessment of flood hazard areas at a regional scale using an index-based approach and Analytical Hierarchy Process: Application in Rhodope-Evros region, Greece,” *Sci. Total Environ.*, vol. 538, no. December, pp. 555–563, 2015, doi: 10.1016/j.scitotenv.2015.08.055.

[18] N. N. Kourgialas and G. P. Karatzas, “A national scale flood hazard mapping methodology: The case of Greece – Protection and adaptation policy approaches,” *Sci. Total Environ.*, vol. 601–602, pp. 441–452, Dec. 2017, doi: 10.1016/j.scitotenv.2017.05.197.

[19] N. N. Kourgialas and G. P. Karatzas, “Flood management and a GIS modelling method to assess flood-hazard areas - a case study,” *Hydrol. Sci. J.*, vol. 56, no. 2, pp. 212–225, 2011.

[20] L. Gigović, D. Pamučar, Z. Bajić, and S. Drobnjak, “Application of GIS-Interval Rough AHP Methodology for Flood Hazard Mapping in Urban Areas,” *Water*, vol. 9, no. 6, p. 360, May 2017, doi: 10.3390/w9060360.

[21] R. Gentile, C. Galasso, Y. Idris, I. Rusydy, and E. Meilianda, “From rapid visual survey to multi-hazard risk prioritisation and numerical fragility of school buildings,” *Nat. Hazards Earth Syst. Sci.*, vol. 19, no. 7, 2019, doi: 10.5194/nhess-19-1365-2019.

[22] I. D. Moore, P. E. Gessler, G. A. Nielsen, and G. A. Peterson, “Soil Attribute Prediction Using Terrain Analysis,” *Soil Sci. Soc. Am. J.*, vol. 57, no. 2, pp. 443–452, Mar. 1993, doi: 10.2136/sssaj1993.03615995005700020026x.

[23] P. Mattivi, F. Franci, A. Lambertini, and G. Bitelli, “TWI computation: a comparison of different open source GISs,” *Open Geospatial Data, Softw. Stand.*, vol. 4, no. 6, 2019, doi: https://doi.org/10.1186/s40965-019-0066-y.

[24] NASA, “Giovanni,” *Global Precipitation Measurement*, 2022. .

[25] Geospatial Information Agency (BIG), “DEMNAS,” 2022. .

[26] C. Palm, P. Sanchez, S. Ahamed, and A. Awiti, “Soils: A Contemporary Perspective,” *Annu. Rev. Environ. Resour.*, vol. 32, no. 1, pp. 99–129, Nov. 2007, doi: 10.1146/annurev.energy.31.020105.100307.

[27] P. Wang and J. J. Feddema, “Linking Global Land Use/Land Cover to Hydrologic Soil Groups From 850 to 2015,” *Global Biogeochem. Cycles*, vol. 34, no. 3, Mar. 2020,

doi: 10.1029/2019GB006356.

[28] D. Priambodo, E. Suhartanto, and S. Sumiadi, “Analysis of Runoff Curve Number Distribution into Surface Runoff of Lesti Watershed,” *Civ. Environ. Sci.*, vol. 004, no. 01, pp. 062–075, Apr. 2021, doi: 10.21776/ub.civense.2021.00401.6.

[29] D. Stewart, E. Canfield, and R. Hawkins, “Curve Number Determination Methods and Uncertainty in Hydrologic Soil Groups from Semiarid Watershed Data,” *J. Hydrol. Eng.*, vol. 17, no. 11, pp. 1180–1187, Nov. 2012, doi: 10.1061/(ASCE)HE.1943-5584.0000452.